METALLURGIA

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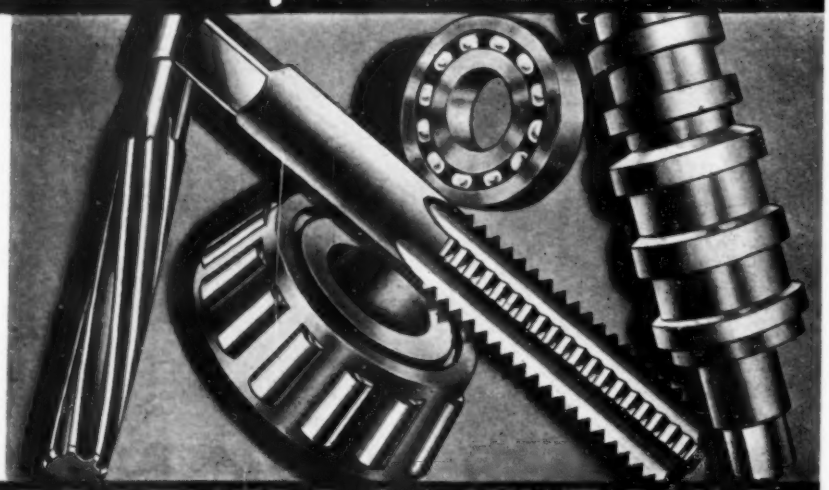

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Third Report of the Oxygen Sub-Committee of the Committee on the Heterogeneity of Steel Ingots

Since the publication of the Second Report of the Oxygen Sub-Committee, the work of the co-operating members has been concerned mainly with a more detailed study of existing methods for determining the gases (oxygen, hydrogen and nitrogen) in steel, rather than with developing new ones, and the additional knowledge presented in this Report is a definite advance on previous conceptions of those methods. As formerly, the Report is sectionalised under the various methods investigated. It forms part of the work of a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation for the Industrial Research Council, and was presented at the recent Annual General Meeting of the Iron and Steel Institute. A general summary of the Report is given in this article.

THE incidence of the war has interfered considerably with the prosecution of the work of the Oxygen Sub-Committee, but sufficient has been done since the publication of the Second Report, which appeared as Section VI of the Eighth Report of the Heterogeneity of Steel Ingots,[1] to warrant the presentation of this Report. It is concerned with the existing methods of determining the gases in steel, rather than in developing new ones, and the additional knowledge presented can be regarded as a definite advance on previous conceptions of those methods. The report is sectionalised under the various methods studied, and the respective authors describe the essential items on which advance has been made, and state the possibilities and limitations of the respective methods as they are practised to-day.

Section II
The Vacuum Fusion and Vacuum Heating Methods

In the first part of this section Mr. H. A. Sloman deals with the vacuum fusion method for the determination of oxygen, nitrogen and hydrogen in steel. This method depends fundamentally on the affinity of carbon for oxygen and its ability to decompose oxides at high temperatures with the formation of carbon monoxide. These reactions are of the balanced equilibrium type, and it is accordingly necessary not only to carry out the determination at a high temperature, but also to remove the products rapidly and completely if total reduction of the oxides is to occur. From the quantity of carbon monoxide produced and the weight of sample taken the oxygen content of the steel is determined.

The developments in vacuum fusion equipment are described, and a comparison made of the forms of equipment in use in the co-operating laboratories, while the fundamental work, which has been carried out in a critical examination of the method at the National Physical Laboratory, is surveyed. In the latter work it was first shown that the results obtained by this method, on many different commercial steels, were reproducible. Where this was not so, it could always be traced to segregation—such, for instance, as occurs in rimming steels, where the result depends on the position in the specimen from which the sample is taken—or to trapped slag. With one reservation it was found that several samples, either of the same steel or of different ones, could be reduced one after the other in the same crucible with consistent results, and that the order in which the samples, in the case of different steels, were introduced into the crucible was immaterial. The reservation referred to steels containing over, say, 1% of manganese or aluminium.

The reproducibility of the results on different samples of the same iron or steel is very striking and is of the same order no matter whether the different samples are reduced in the same apparatus at any one laboratory or divided between two or more. The range of total oxygen content with which one is normally concerned is from about 0·002% to about 0·03%, and provided that the weights of samples are adjusted to give reasonable volumes of gas for subsequent analysis, the order of error is about ± 0·0005% to about ± 0·001% over the above range of oxygen contents. In the case of the special work on oxygen-free high-purity iron carried out at the National Physical Laboratory, duplicates of the type 0·0004 ± 0·00005% of oxygen have been obtained.

This method is compared with the aluminium-reduction method. In the latter the oxides are converted into alumina by melting the steel sample in the presence of excess aluminium at about 1,150° C., and estimating the oxygen chemically as alumina. Of the two methods the aluminium reduction method gives total oxygen only, whereas the vacuum fusion method gives not only oxygen, but also hydrogen and nitrogen. The fractional form of the latter method may eventually be proved to go even further, and split, with reasonable accuracy, the total oxygen into its constituent components. It seems probable that the aluminium reduction method is somewhat more rapid than the vacuum fusion method, but against this must be set the fact that only one analysis can be made in the former, as against a large number in the latter. This disadvantage is, however, largely off-set by the relative cheapness and simplicity of the equipment required in the former method, which would permit several furnace tubes to be set up and run concurrently, if required.

The importance of recognising the presence of "surface oxidation" is emphasised, it being shown that this may account for as much as 0·004% to 0·006% of oxygen on pure iron. Nitrogen results obtained by the vacuum fusion method have provided some interesting new data

when studied in conjunction with those obtained by chemical methods, whereby some indication is given of the form of existence of the nitrogen in the steel. The hydrogen content of steel is being regarded with increasing interest, and determination by vacuum heating (as distinct from vacuum fusion) is being extended.

In the course of the production of high-purity low-oxygen iron, a combination of microscopic examination and the vacuum fusion method has resulted in a more accurate knowledge of the solubility limit of oxygen. It is indicated that this lies between 0·006% to 0·003%.

The Fractional Vacuum Fusion Method

The position of the fractional vacuum fusion method for the separation of oxides and gas in steel is discussed by Dr. T. Swinden, Mr. W. W. Stevenson, and Mr. G. E. Speight, and typical results obtained by this method are given and are compared with results obtained by the alcoholic iodine and chlorine methods. This method is based on the fact that the constituent oxides in steel are not all equally readily reduced by carbon, and therefore, by carrying out a series of partial reductions at different temperatures from about 1,080° C. upwards, it is hoped that the oxides will be reduced separately in the order, FeO, MnO, SiO_2 and Al_2O_3.

Detailed comments on the significance of the fractional results were made by the authors and published in the Eighth Report of the Heterogeneity of Steel Ingots, but they reiterated the following points:

1. The fractional result for iron oxide is usually lower than that of the residue methods in steels containing a preponderance of silicate non-metallics; in unskilled steels of the rimming type, the fractional result is usually higher in iron oxide than that obtained in separated residues.
2. A higher figure for manganese oxide is usually obtained by the fractional method than by residue procedures.
3. Steels containing complex silicates tend to give slightly low silicate results by the fractional method, which fairly readily recognises such non-metallics by their comparative slowness of reduction at the temperature of the silica fraction.
4. Fractional alumina results are usually lower than those obtained by residue methods. This may be due to the separation by the residue methods of compounds of aluminium other than oxides, and further investigation of this possibility is in hand by the Sub-Committee.

The Determination of Hydrogen by Vacuum Heating

Dr. W. C. Newell briefly summarises his further data on this subject. He has already published a paper[2] giving details of an apparatus which he designed and constructed for the determination of hydrogen in steel by heating in a high vacuum at a temperature of only 600° C. The rate of evolution of hydrogen from steel over a range of temperature from 400° to 900° C. was explored, and the total hydrogen given off was shown to be independent of the temperature. A careful comparison was made of the results obtained by this method and those by the author's vacuum-fusion apparatus, and a number of results were given for different types of steel, showing that there is a good agreement.

Since the publication of the above paper, the single-stage mercury-vapour pump has been replaced by a similar two-stage pump. Whilst the pumping rate is thereby improved and the degree of vacuum attained is presumably higher, no difference has been observable in the performance of the apparatus, which has continued to be used in a highly satisfactory manner for fundamental research work upon the hydrogen-iron system.

Section III
The Aluminium Reduction Method

As an alternative method to vacuum fusion for the determination of total oxygen alone, attention is directed to the aluminium reduction method introduced by Mr. N. Gray and Mr. M. C. Sanders. In this paper these authors detail the improvements introduced in the method since it was originally described, notably whereby the atmosphere of hydrogen is dispensed with and the determination carried out under reduced pressure. Results obtained by the aluminium-reduction method in hydrogen on various steels on which the oxygen content had previously been determined by vacuum fusion, show excellent agreement with the latter when applied to carbon steels. The oxygen content in known weights of various oxides and compounds has been recovered in this way. A further study of the method on a wide variety of materials is being undertaken.

The aluminium-reduction method has been in regular use for some time in the Central Research Department of the United Steel Companies Ltd.; and in Part B of this section Mr. Stevenson and Mr. Speight describe their equipment and their experience on a series of steels which confirms very good agreement with the vacuum-fusion method; the aluminium reduction results being all slightly on the low side after applying the blank correction. When no blank correction is made, agreement with the vacuum-fusion method on the steel examined is very close.

Further work on the aluminium-reduction method is dealt with in Part C of this section, in which Mr. E. Taylor-Austin describes a modified method applied to the determination of total oxygen in pig iron. The experimental work in this connection has led the author to make the following conclusions:

1. The modification introduced successfully obviates any interference arising from the presence of silicon in the original material.
2. The modified reduction method can be applied to the determination of the total oxygen content of pig irons generally, provided that a suitable sample can be obtained.

Section IV. The Chlorine Method

The chlorine method is one of the "residue" methods by which the non-metallic inclusions are separated chemically from the iron, and are submitted to chemical analysis. In the first part of this section Mr. E. W. Colbeck, Mr. S. W. Craven, and Mr. W. Murray describe their further work on the chlorine method. The latest type of equipment and the details of procedure are carefully explained, as well as an improved technique in the analysis of the residue.

In the second part of this section the same authors show the satisfactory application of the method to a wide variety of steels. Good agreement in the total oxygen figures obtained by the chlorine method and the vacuum-fusion method was obtained on fully-killed carbon steels. In the case of rimming steel, lower results are obtained by the chlorine method, and, in explanation, the authors suggest that:

(*a*) The inclusions present in rimming steel may be susceptible to attack by chlorine at 350° C., perhaps, because of the fact that in this type of steel they consist largely of FeO and MnO, present as such, and not linked with appreciable amounts of SiO_2 or Al_2O_3 as in killed steels.

(*b*) There is considerable controversy as to whether oxygen exists in "solid solution" in steel. If it is present in rimming steels in such a form it is probable that it would not be retained in chlorine residues, although it would be extracted by the vacuum-fusion procedure.

In their earlier work[3] the authors showed that the chlorine method was very promising for certain alloy steels which contained elements known to interfere seriously with the iodine method, and reference is made to further work which is being pursued in the application of the chlorine method to alloy steels.

Section V. The Alcoholic Sodium Method

This method can be used for the determination of oxides in low- and medium-carbon steels not containing appreciable

amounts of elements which form stable carbides or insoluble iodides. Such steels represent a large proportion of the total tonnage of manufactured steel. In the first part of this section Mr. T. E. Rooney summarises concisely the present position of this method for which he has been so largely responsible. It embraces the work carried out at the National Physical Laboratory, and in the collaborating laboratories. The method as now practised and described in this paper includes the various modifications introduced since the last Report, and can now be regarded as proved and accepted for the accurate determination of the oxide-containing inclusions in low and medium straight carbon steels.

The limitations of the method are discussed. For instance, difficulties have been experienced in dealing with aluminium-killed steels, and some to which aluminium has been added. The difficulty probably arises owing to the retention of undecomposed aluminium carbide and/or aluminium nitride in the oxide residue after treatment with the iodine solution. The low solubility of iron carbide in the iodine solution is another factor which limits the applicability of the method. Alloy steels containing appreciable amounts of elements such as chromium, vanadium, titanium, etc., which form stable carbide, or elements such as titanium and molybdenum, the iodides of which are insoluble in alcohol, when treated by the standard procedure yield residues which contain an undue proportion of material other than oxides. Certain steels have been examined which yield variable results for the MnO fraction.

The interference either proved or anticipated from elements forming stable carbides or insoluble iodides is recognised, and is being made the subject of further study. As the author points out, it is not unusual for an accepted method to be modified to suit different types of material, and certain modifications are proposed for the application of the alcoholic method to rimming, to which further reference is made in Section IX.

The successful use of alcoholic iodine solution for stripping oxide films on iron is mentioned. The work of the last Report has naturally been directed mainly towards overcoming the limitations of the method, and this work has given rise to some interesting thoughts on the form of existence of certain elements in the steel—e.g., aluminium and phosphorus. Sheffield University has done considerable research on the interference by carbon, and has indicated the limits beyond which carbon interferes with the accuracy of results. Phosphorus has also had considerable attention, and this has led to the necessity for thoroughly drying the alcohol.

In the second part of this section Mr. W. W. Stevenson and Mr. G. E. Speight describe a simplification of the alcoholic method which, nevertheless, fulfils all the essentials and appears to produce results of sufficient accuracy for practical purposes, subject, of course, to the limitations previously mentioned. The method has been adopted for the determination of oxide residues in killed steels in the Central Research Department of The United Steel Companies Ltd., and a number of results obtained are given in this paper. In many cases oxygen values by the vacuum-fusion technique are also recorded, and comparison with the standard procedure is shown in the results for a transformer steel.

Section VI. The Aqueous Sodium Method

The British Cast Iron Research Association has collaborated in investigating particularly the use of the aqueous iodine method and Mr. E. Taylor-Austin surveys the possibilities and limitations of a revised method, especially with reference to the determination of oxide inclusions in pig iron. Since the publication[4] of the original modified aqueous iodine method, the wider application of the procedure has led to the introduction of certain modifications. A study of the variations in hydrogen-ion concentration during the decomposition of pig-iron samples has provided an explanation for the apparently anomalous behaviour of synthetic manganous oxide towards the iodine solvent, and has also demonstrated the futility of carrying out experiments on synthetically-prepared oxides, sulphides, etc., in the absence of iron.

A study has been made of the behaviour of iron carbide during the process, and it has been shown that no interference is set up by this compound. The behaviour of titanium carbide and manganese sulphide has also been examined, and there is evidence that the small traces of phosphorus hitherto found in the final non-metallic residues is in some way connected with titanium and not, as was at one time thought, with calcium and/or magnesium.

The revised procedure, which has now been successfully applied to a series of over 40 pig irons, is described in detail, and from the work carried out the following conclusions are drawn :

1. The solution of manganous oxide, as such, during the decomposition of samples by aqueous iodine/potassium-iodide cannot be prevented, and hence results for this oxide cannot be obtained at present.
2. Iron carbide, iron phosphide, manganese sulphide and titanium carbide cause no interference in the new procedure.
3. The modifications introduced surmount the difficulties which had arisen during the more general application of the method originally suggested.
4. The present procedure has been successfully applied to a series of 45 different types of pig iron without futher complications ; it is therefore believed that the process may be employed for the determination of oxide inclusions in all types of pig iron, excluding alloy irons, and that results for SiO_2, FeO, MnO (existing as manganese silicate) and Al_2O_3 are reliable.

In the second part of this section, Mr. J. G. Pearce presents a general review of the present position of the determination of oxide inclusions in pig-iron and cast iron. Reference is made to disparities between chemical evidence and microscopic evidence of oxide inclusions, and it is suggested that the contradictions are more apparent than real.

Section VII. The Hydrogen Reduction Method

The hydrogen reduction method has been the subject of intermittent attention for many years. Interest has been reviewed in the possibility of accurately determining the more readily reducible oxides, and Mr. W. W. Stevenson briefly refers to experimental work, which has been proceeding at the Central Research Department of The United Steel Companies Ltd., on the suitability of this method for determining that part of the oxygen content of steel which corresponds to the low-temperature fraction of the fractional vacuum-fusion method. A number of refractory materials have been employed for the furnace tube without obtaining a sufficiently low blank value to render the procedure scientifically attractive. It has been mentioned that transparent silica is far more stable towards reduction by hydrogen than any of the refractory tubes on which experiments have yet been made in this connection, and it is planned to continue the work with this material.

Section VIII
The Analysis of Non-Metallic Residues Extracted by the Alcoholic Iodine Method

The technique of the analysis of residues is obviously important, and in this paper Mr. G. E. Speight suggests, improvements in the direction of the almost complete adoption of colorimeter methods. The methods of analysis which have now been adopted for ignited non-metallic residues may be summarised as follows :

Silica is determined by digestion of the residue with strong acids or fusion with potassium or sodium bisulphate, followed by filtration, ignition and treatment with hydrofluoric and sulphuric acids.

The oxides of iron, titanium, vanadium and zirconium (if present) are precipitated by cupferron in the acid filtrate from the silica precipitate. The residue is ignited, fused with potassium bisulphate and extracted in dilute sulphuric acid. Aliquot portions of the resulting solution are taken for the colorimetric determination of:

Iron, by the thioglycollic acid procedure.
Titanium, by hydrogen peroxide.
Vanadium, by hydrogen peroxide.

A test for zirconium is carried out by precipitation of its phosphate in dilute sulphuric acid solution with ammonium phosphate.

The cupferron in the filtrate is destroyed, and aluminium and chromium are precipitated by 8-hydroxyquinoline in buffered solution. The precipitate is redissolved, and portions of the resulting solution are taken for the determination of aluminium by aurintricarboxylate, and chromium by diphenyl carbazide. Manganese and phosphorus are determined in the filtrate (after destroying the 8-hydroxyquinoline by nitric and sulphuric acids) by the colour reactions with potassium periodate and ammonium-molybdate/stannous-chloride, respectively In cases of high phosphorus-pentoxide contents, it is sometimes preferable to use the gravimetric lead-molybdate procedure.

Section IX. Reports on Materials Examined

In the first part of this section the results of an examination of the oxygen content of a basic Bessemer rimming steel are presented by Dr. T. Swinden and Mr. W. W. Stevenson. This examination comprises (*a*) microscopical examination, (*b*) chlorine extraction, (*c*) alcoholic iodine extraction, and (*d*) vacuum-fusion determination by both the total and fractional procedure. These results confirm the view that the residue methods tend to give low results, which, it is suggested, are due to the attack of the halogen reagent on uncombined iron and manganese oxides. It would appear that the fractional extraction method, as previously mentioned, is well suited for the fractional determination of oxygen in this type of steel.

The second part is a note on the examination of a series of carbon steels by Dr. W. R. Maddocks. The investigation was undertaken to ascertain the influence of carbon on the alcoholic iodine extraction method for the determination of oxygen in steel. A series of carbon steels containing from 0·10% to 1·13% of carbon was chosen. Oxygen determinations were carried out on these steels in the normalised, quenched and spheroidised states.

The results obtained so far indicate that the amount and state of the carbon present have an influence on the iron-oxide fraction of the residue. Normalised high-carbon steels give iron-oxide fractions which are much greater than would be expected. All the steels with more than 0·45% of carbon, examined in the quenched state, give higher iron-oxide fractions than in the normalised condition. Steels with less than 0·45% of carbon appear to give the highest value for the iron-oxide fraction after spheroidisation.

An interesting feature of the work is that the P_2O_5 fraction of the residue is always greater in the quenched steels than in those that are normalised. The lowest values were always obtained from the spheroidised samples.

It is felt that misleading conclusions would be drawn from the work if it were published in its present form.

The Report concludes with a general summary by Dr. T. Swinden, chairman of the Oxygen Sub-Committee, and also a section devoted to work in hand and future programme. As stated in the last paragraph of the Report, the war conditions under which a good deal of this work has been carried out naturally have had their effect on the progress of these researches. It is, indeed, gratifying to be able to present a report at all under these circumstances, but it is in the certain belief that this work is of vital importance to the fuller understanding of the physical chemistry of steelmaking and all that this means in avoiding trouble and improving quality, that one is inspired to find the necessary time to pursue what might otherwise be regarded as an academic piece of work suitable only for peace-time pursuit.

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[1] *Iron and Steel Institute*, 1939, *Special Report No.* 25, pp. 37-234.
[2] *Journal of the Iron and Steel Institute*, 1940, No. I., p. 243P.
[3] Eighth Report on the Heterogeneity of Steel Ingots, Section VI., Part 4, subsection *B*, p. 111, *Iron and Steel Institute*, 1939, *Special Report No.* 25.
[4] Eighth Report on the Heterogeneity of Steel Ingots, pp. 121-138, *Iron and Steel Institute*, 1939, *Special Report No.* 25.

Control of Ball and Roller Bearings

THE Control of Ball and Roller Bearings (No. 1 Order), which comes into force on April 30, prohibits the purchase or acquisition of any ball or roller bearing except from the bearing manufacturers, or for use by the purchaser in production or maintenance of some other article, or under a Licence issued by the Minister of Supply. Copies of the Order can be obtained from H.M. Stationery Office, York House, Kingsway, W.C. 2, or through any bookseller, price 1d.

All inquiries should be addressed to the Bearing Panel, Ministry of Supply, Gt. Westminster House, Horseferry Road, S.W. 1.

Institute of British Foundrymen

Annual General Meeting

THE annual General meeting of the Institute of British Foundrymen will be held at the Midland Hotel, Manchester, on July 12, 1941. Following the usual business meetings two technical sessions will be held for the presentation and discussion of the following papers:

SESSION A.

"American Synthetic Sand Practice," by N. J. Dunbeck. This paper will be presented by J. J. Sheehan, A.I.C., on behalf of the American Foundrymen's Association.

"Mould and Core Washers; Their Preparation and Possible Methods of Testing," by W. Y. Buchanan.

SESSION B.

"Moulding Steam Valve Lids for Marine Service," by F. Hudson.

"British National Specifications for Cast Iron," by J. G. Pearce, M.Sc., F.Inst.P; presented on behalf of the British Cast Iron Research Association.

These technical sessions will proceed simultaneously.

In connection with the meeting a luncheon has been arranged; tickets are 5s. 6d., and those wishing to attend are asked to make application for tickets prior to June 30, 1941, to Institute of British Foundrymen, St. John Street Chambers, Deansgate, Manchester, 3.

E. J. Fox Gold Medal

The Council of the above Institute has accepted the recommendation of the Assessors (Sir Wm. J. Larke, K.B.E., and Dr. J. E. Hurst) to award the E. J. Fox Gold Medal for 1941 to Mr. Percy Pritchard, in recognition of the scientific and technical contributions which he has made to the development of the foundry industry, particularly in light aluminium and magnesium alloys. Mr. Pritchard is managing-director of the Birmingham Aluminium Company Ltd., the Midland Motor Cylinder Company Ltd., and Birmid Industries Ltd.

Obituary

We regret to announce the death of Mr. W. W. Myers, in his sixtieth year. Mr. Myers held the position of office manager with The Carborundum Company Ltd. for many years, in which capacity his kindly and sympathetic nature made him the most popular member of the staff. His passing means to the staff the loss of a friendly adviser, and brings to an end a long and loyal service to the firm.

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Plastic Theory—Its Application to Design

THE need for economy in the use of materials was never so important as at the present time, but if the structural engineer is to achieve this economy it is essential that he should adopt rational methods of design, a course which is only possible when there is adequate knowledge of the behaviour of structures under all conditions of loading. With a view to producing eventually more rational methods of design for steel-frame structures with fixed connections, model beams and frames have been listedto determine their true strength, and the results obtained are discussed by Professor J. F. Baker and Mr. J. W. Roderick, in a recent paper presented to the North-East Coast Institution of Engineers and Shipbuilders.

In a steel framework not only is it necessary to study the elastic range in which deflection is proportional to applied load, but also that beyond beginning with the first signs of yield and ending with the collapse of the structure as a whole. Until recent years this range had received little attention, but with the formulation of a plastic theory for metals it has become the subject for much investigation, and there is every reason to believe that a wise application of this knowledge will lead to considerable economy in the design of certain types of structures, in particular the welded steel frame.

As yet there exists no method for the design of welded-frame structures, which is both rational and economical. The nearest approach to these requirements are the recommendations for design set out in the Final Report of the Steel Structures Research Committee,* but these, unfortunately, are severely handicapped by the existing maximum allowable stresses. Most regulations governing the design of welded structures contain a clause to the effect that, where the connections are virtually rigid and designed to be capable of transmitting the full moments and shears which are set up at the joints, the design should make allowance for the stresses set up in other parts of the structure. The position, therefore, is that the designer of a rigid frame has no alternative but to take full account of the true stress distribution in his structure, yet he receives little or no recompense in the shape of increased permissible stresses.

Design of steel-frame structures has always been according to what is generally known as a working stress method. For instance, the joists of a steel frame building have, until recently, been proportioned so that the maximum working load they are required to carry will produce a stress not exceeding 8 tons per sq. in. It is tacitly assumed that the structure will reach the limit of safety as soon as the stress at any point within it becomes equal to the yield value of the material, for the case in question approximately 16 tons per sq. in., so giving a factor of safety of 2. Such an assumption is reasonable for a pin-jointed structure, since collapse takes place comparatively soon after yielding commences. If, however, rigid connections are introduced, the conditions are somewhat different in that the first signs of yield do not indicate the imminent collapse of the structure. Collapse is, in fact, considerably delayed. The greater the degree of redundancy of the structure, the greater is this delay.

Highly redundant structures which will react in this manner under load are employed in aircraft. When designing aeronautical structures a factored load is used in preference to a working stress, the maximum working loads are first multiplied by a factor to give some desired margin of safety and the subsequent requirement is that the structure shall be able to carry this factored load without collapsing. The essential point of such a method is that it admits of local yielding at high loads, which causes definite redistribution of stress within the structure It is in this way that design based upon a factored load scored over the more usual working-stress method which is dependent only upon the behaviour of the structure under the action of the working loads.

Whatever method of design may eventually be evolved for steel-frame structures of the welded type, whether it be a method based upon a working stress of increased value or a method employing load factors, it is imperative that the behaviour of these structures at all stages, right up to the point of collapse, should be clearly understood. The elastic range has been investigated with some completeness by the Steel Structures Research Committee, but the semi-plastic range, that existing after the yield has taken place at one or more sections, still remains largely an unknown quantity.

A considerable amount of attention has been given in recent years, mainly in European countries, to the development of a theory of plasticity. It is, however, where it concerns structures, incomplete and speculative, largely unsupported by experiment, except for such pioneer work of Maier-Leibnitz on beams. Professor Baker and Mr. Roderick have undertaken an investigation for the Institute of Welding with the primary object of determining the carrying capacity of steel-frame structures. The information cannot be obtained by mathematical analysis unsupported by experimental work. The testing to destruction of full-scale structures is both difficult and expensive. Attention is therefore being paid to the study of the behaviour of small-scale members and frames, and eventually it is intended to check these results, together with any analysis or design method arising out of them, by a few full-scale tests.

The tests carried out have been concerned entirely with the behaviour of beams, both in the simply supported condition, and as an integral part of a structure where the extremities are held with a certain degree of fixity. From the tests described in this paper, it is evident that for the first condition collapse will occur when the transverse loading is sufficient to produce complete plasticity at some section within the span, its position depending upon the arrangement of loading. As far as can be ascertained from tests on portal frames, it appears that when a beam becomes a member of a structure having fixed joints, collapse will not occur until complete plasticity has been attained both at some section within the span and at the ends of the beam or adjacent ends of those members restraining the beam. These two statements form the principal conclusions which can be drawn from the investigations as far as it has proceeded; and although the point has not been reached at which rules can be formulated for design, sufficient information is forthcoming to indicate the lines along which the task may be approached.

* H.M. Stationery Office.

By far the most interesting part of this investigation is the study of the beam as a member of a structure having fixed points, for it is in this direction that economy should result from the use of the plastic theory in design. It has been demonstrated that such a beam, by reason of the fixity of its extremities, is able to carry far more load before collapse takes place than is so in the simply-supported condition. Moreover, with this restraint the load for collapse will be, in certain circumstances, considerably greater than that required to produce the first signs of yield. Hence, if design is based upon collapse load, rather than on the first signs of yield, as is conventional, a marked economy is material should result. But this will only be possible if regulating authorities are prepared to permit much higher stresses under the working load.

The Iron and Steel Institute

Annual General Meeting held in London

The importance of the iron and steel industries was emphasised by Mr. Menzies at a luncheon held in connection with the Annual Meeting of the Iron and Steel Institute, at which the guests formed a very distinguished company. Extracts of speeches are given together with brief references to the official business and to the technical session which was held.

THE Seventy-Second Annual Meeting of the Iron and Steel Institute was held at Grosvenor House, London, W., on May 1, 1941, Mr. John Craig, C.B.E., President, occupying the chair. Owing to the war the proceedings, which began with a luncheon followed by a session for the transaction of official business and the discussion of papers, was limited to the one day.

At the luncheon, which took the place of the usual annual dinner, nearly 600 members and guests were present. Among those who accepted invitations were: The Rt. Hon. R. G. Menzies, P.C., LL.D., Prime Minister of Australia; H. E. M. Bjorn Prytz, Swedish Minister and Mme. Prytz; H. E. M. C. Simopoulos, Greek Minister, and Mme. Simopoulos; Sir Andrew Duncan, G.B.E., M.A., LL.D., Minister of Supply; the Rt. Hon. Lord Hankey, P.C., G.C.B., G.C.M.G., Chancellor of the Duchy of Lancaster; H. E. M. Josef Bech, Minister of Foreign Affairs, Luxemburg; Field-Marshal Lord Milne, G.C.B., G.C.M.G., D.S.O.; His Excellency M. Ivan Soubbotitch, Yugo-Slav Minister and Mme. Soubbotitch; Colonel J. J. Llewellin, C.B.E., M.C., T.D., M.P., Parliamentary Secretary, Ministry of Aircraft Production; Marshall of the Royal Air Force, Viscount Trenchard, G.C.B., G.C.V.O., D.S.O., and Viscountess Trenchard; the Rt. Hon. S. M. Bruce, C.H., M.C., High Commissioner for Australia, and Mrs. Bruce; Lt.-Gen. Sir John Brown, K.C.B., D.S.O., C.B.E., Deputy Chief of the Imperial General Staff; Sir William Larke, K.B.E., Vice-President, Director, British Iron and Steel Federation; Mr. W. J. Jordan, J.P., High Commissioner for New Zealand; Sir William Bragg, O.M., K.B.E., F.R.S., Director, Royal Institution; Brig.-Gen. Sir Harold Hartley, C.B.E., F.R.S., Vice-President, L.M.S. Railway, and Lady Hartley; Engineer-Vice-Admiral Sir George Preece, K.C.B., Chief Engineer to the Fleet, and Lady Preece; Sir Henry Dale, C.B.E., F.R.S., President, Royal Society, and Lady Dale; Sir E. V. Appleton, F.R.S., Secretary, Department of Scientific and Industrial Research, and Lady Appleton; and the Presidents of many allied institutions.

Presentation of Bessemer Gold Medal

At the luncheon and following the loyal toast, the President presented the Bessemer Gold Medal for 1941 to Dr. Thomas Swinden. In doing so, he said it was a great pleasure and a great honour. The Council had determined with complete unanimity, and those who knew Dr. Swinden will realise that the Council has acted not only wisely but well in selecting him for such a high honour. Dr. Swinden's work in connection with tungsten steel, and his close study of molybdenum in steel are well known. His most important recent work is an investigation into the properties of cold-rolled steel and the control of grain size. His work in improving the quality of the products of the iron and steel industry, however, has not been confined to the theoretical study of the problems of the industry; he has built up one of the finest research organisations in the country, has taken a leading part in the direction of organised research for the industry, and is chairman or vice-chairman of numerous research committees. He has also rendered great service to the country by giving advice which has proved of the utmost value to various controls.

Continuing on a more personal note, the President said that if there was one town which had a thorough knowledge of the steel trade that town was Sheffield, yet, even in that enlightened town Dr. Swinden had shed further light, and he thought that those engaged in the industry in Sheffield would be very willing to join in doing honour to Dr. Swinden on the present occasion.

In acknowledging the award, Dr. Swinden said that in normal times the recipient of the Bessemer Gold Medal availed himself of the opportunity afforded by its presentation to say something of his work and aspirations, but that was not possible in the present circumstances. He was permitted, however, to say how deeply sensible he was of the very great honour which had been conferred upon him and to thank the President for the all-too-kind terms in which he had referred to the work for which the Council had thought him worthy of the award. The fact that the medal was a token medal might, in fact, be of considerable historic interest in the future. In common with many previous recipients, he regarded the award not only as a personal one, but as a recognition of the efforts of those for whom and with whom he had had the honour and pleasure of working for so many years. He regarded the award as an incentive to further service for the Institute and the industry, and that he would do his utmost to render that further service.

The Iron and Steel Institute and Industries

The Rt. Hon. R. G. Menzies, P.C., K.C., LL.D. (Prime Minister and Minister for Co-ordination of Defence, Australia), in proposing the toast of "The Iron and Steel Institute and Industries," made a characteristic speech. Among other points he emphasised, he said: "There was a time, many centuries ago when wars were fought by small bodies of men, and when communities went on their ordinary way, sometimes hardly conscious that a war was being fought; but, as time has passed, as technique has developed, and as scruples have become less, war has spread its net farther and farther, until at this time we find ourselves engaged in a war that has been called a 'total war,' in which no one who is within range of any instrument of death can regard himself or herself as being on anything other than active service. The people of this country, for example, are without exception at war and in war, and more and more as time goes on they realise, just as we who are further away in Australia and people on the American continent begin to realise, that to win a total war you must have a total organisation of every resource that you have.

"This is a war in which the factory, the organisation, the machine, are much more important than at any time before in the world's history. I do not know whether there are any of us left in the British world who still want to talk in terms of numbers, who still want to think in terms of divisions, who still want to work out mathematical calculations about the total man-power; but, if there are, let us abandon that habit while there is yet time. We have to estimate our strength in this war by asking ourselves just what industrial power translated into terms of machines of war, we can put into the hands of our soldiers.

"In this war the efficacy of a British Army, whether from the United Kingdom, from Australia, from New Zealand, from South Africa or from Canada, will depend not only on the courage and skill of the men who compose it, but also, and mightily, upon the number of tanks, vehicles and guns with which we have been able to equip them. I venture so say, therefore, that, properly understood, this is, above all other wars, an *industrial* war; and the work being done by the heavy industries of the British world is therefore seen to be the most vital work, so vital that I am not sure that everyone in the iron and steel industry should not be regarded as being on active service.

"Speaking on behalf of one Government in the British Empire, I want to say that nothing can ever adequately express the debt of Governments and the debt of peoples to the great iron and steel industries, not only of Great Britain, but of the British world. My country could not at this moment be progressing as she is in all forms of engineering production for war if it were not for the iron and steel industry of Australia. Never a week goes by in my office in Australia when I do not feel or express gratitude for the wisdom of those men who decided that for the security of Australia, to enable her to play her full part should any trouble occur in the world, there should be laid down firmly and broadly the foundations of heavy production.

"When some historian of the future looks back on the records of this war, and when in a freer world and a happier time, he writes the story of what has occurred in these years, he will perhaps remember some things which appear at the moment to be transient. He will remember some great speeches made by some great men in this county. He will remember some magnificent decisions taken by Parliament in this country. He will remember—nobody would ever dream of forgetting—the superb courage and spirit shown by men who fight for this country, and by the women who fight for this country. He will remember all these things; but, I believe, above all he will say that in the war the real foundations of success were laid by those who did not think that they were on active service, who had no uniform, who worked in grimy overalls juggling with large masses of molten metal, because, he will say this was the beginning of an age in which the industries of a country were seen to be among the great fighting services of that country. When that has been recorded, I believe that the position of the iron and steel industry, and the relation of large-scale industry to the conduct of the affairs of the State will have been seen in a new light, and that we shall go forward into a period when politics will not be regarded as the eccentricity of a few people, but will be seen as a sphere of activity in which the great men of industry will be recognised as great men of their country and great men of affairs.

"It is a very great pleasure and a very great honour to submit to you the toast of 'The Iron and Steel Institute and Iron and Steel Industries.'"

The President (Mr. John Craig), who responded, said: "It is a great honour to us that our Institute should be referred to in the way that it has been by the Prime Minister of Australia. His presence in this country has been to everyone most stimulating and fortifying, and has been a great source of encouragement to all the people of the homeland; it has been a great encouragement to us that someone should come from the Dominions so fortified by ability, enthusiasm, energy and knowledge to help us in this day of trial, and many have gained inspiration by his presence and by his speeches, and have been helped by the conscious power that lies behind him and the great country which he represents. We welcome him here to-day, not only as a great statesman from a great country, but likewise as coming from a great country which has worthily maintained the highest traditions of our industry.

"I can recall the arguments of a few years ago, when those in our industry in the old country were unduly perturbed and made anxious by witnessing the development of the industry in Australia. Nature has been extraordinarily kind to Australia, giving her wonderful iron-ore deposits and all the other requisities for the making of steel with which she has been so richly endowed. It is fortunate that here great industry fell into the hands of people who in fact direct it. We are all well aware and almost envious, of the excellent plant which exists in Australia, and we may admire the men who lead it, and who have taken advantage of all the knowledge which can be gathered in America, on the Continent and in our own country. We are grateful to them for stepping in, and for being so helpful in this great contest.

"It is good to hear the industry spoken of as it has been. As regards the work of the Institute, perhaps to-day there is a better outlook. In the old days it was the skilful speculator who was regarded as the distinguished steelmaker, the man who sized up the markets, and bought and sold. The Institute struggled in those days to uphold the technical and scientific side of the industry, and did so through difficult years; but it has now come into its own. We are now realising more than ever that it is the scientific side of steelmaking which proves of the greatest benefit in time of crisis; it is not how cheaply we can make steel, but how good we can make it which counts to-day. If ever there was a time when good steel was required, it is to-day, and I am thankful to believe that the steel which is being provided for our Services, perhaps not so quickly as some would like, is reliable, and they can trust their lives to it. The technical members of the industry have been greatly encouraged by Mr. Menzies, and I am happy to think that encouragement is given to those who have a technical outlook on life.

"As far as the Institute is concerned, the great work which it did in pre-war years lay in giving to young men a consciousness of the value of research, a feeling that they were never to be satisfied with what was being done, that they were ever to be critical of what their fathers had done, and never to accept what their grandfathers had done as having anything to do with the present, but that they must themselves bring a new mind to bear, and harness the new knowledge constantly placed at their disposal. I trust that the younger man will realise that steelmaking is a very young business, and that what we know about it is infinitesimal compared with what remains to be known. A great many things are being discovered to-day which are quite revolutionary.

"The Guests"

The toast of "Our Guests" was to have been proposed by Lord Dudley, but important duties prevented his attendance at the luncheon, and it was admirably proposed by the President, who coupled with it the name of a good friend from Luxemburg, M. Bech.

His Excellency, M. Josef Bech, Minister of Foreign Affairs of the Duchy of Luxemburg, who responded, said: "It is an honour and a great pleasure to reply on behalf of the guests. I thank your President for the cordial way in which he has proposed this toast, and I regret that I am unable to improvise the words of sincere gratitude in which I should like to express my thanks. I can only say, 'thank you' from the bottom of my heart. Probably I owe the privilege of speaking on behalf of so many distinguished people to two members of this Institute,

Thomas and Gilchrist, the inventors of the basic converter process of steel manufacture, which made it possible for the industry of Luxemburg to rank among the largest iron and steel producers in Europe. I wish here to pay homage to those English metallurgists, whose invention definitely established the prosperity of my country.

"Never in history were there knights of higher spirit fighting for a nobler cause than the soldiers, sailors and airmen of Great Britain, her Dominions and her Allies. The spirit is there, indeed, and, as for the weapons, you, the men of the iron and steel industries, with the magnificent and almost unlimited help of the United States, are making for them the road which leads to victory and salvation.

"In conclusion, I should like to recall that when I last had the honour and pleasure of welcoming the Institute to Luxemburg, a few years ago, I expressed the hope that you would come back soon. I did not then expect that I should be coming to you! You will realise the feelings with which in the present circumstances I repeat the invitation; you cannot come too soon to a free and independent Luxemburg!

"I am sure that I speak for all the guests when I thank the President for your very kind hospitality. In the case of those of us who, like myself, have found such generous hospitality in this country, our gratitude to you and to England is all the more profound. I am happy to propose the health of Mr. Craig, your president. We all know that his eminent qualities of leadership render him equal to the greatest burdens and responsibilities that war brings to one in his high office. I ask you to join with me in wishing him continued health and prosperity in all his undertakings."

The President, after expressing his appreciation of the compliment, went on to say that there was present at the Annual Meeting the former Secretary of the Iron and Steel Institute, Mr. Lloyd, who was eighty years of age. All the members would join in wishing him, in spite of his age, many happy years to come.

Business Meeting

A session for the transaction of official business and for the discussion of certain papers was held immediately following the luncheon, at which Mr. John Craig, C.B.E., President, occupied the chair. After the Minutes of the Sheffield meeting had been taken as read and confirmed, the President made fitting reference to the death of Mr. Albert Peech, and of Mr. Charles J. Walsh. Mr. Peech was a Vice-President of the Institute, and Mr. Walsh a member of the Council. Mr. Peech had linked up the members with the past, and Mr. Walsh with the present, and their death was a great loss to industry.

The Secretary (Mr. K. Headlam-Morley) announced that the Council had awarded the Williams Prize for 1940 to Mr. B. Yaneske for his paper, "The Manufacture of Steel by the Perrin Process,"* which was presented at the Autumn Meeting last year. It was also announced that Andrew Carnegie Research awards had been made by the Council in 1940 to the following candidates: M. Balicki (University College, Swansea), £100 in aid of a research on cold-hardening of steel and verification of the recrystalisation theory put forward by Professor Krupkoffski and the candidate; and H. Morrogh (British Cast Iron Research Association), £100 in aid of a research on sulphide inclusions produced by the neutralisation of sulphur in cast iron by aluminium, copper, nickel, chromium and molybdenum.

Technical Session

Owing to the limited time available only three papers were presented for discussion at this meeeting; these included the "Third Report of the Oxygen Sub-Committee," "The Polishing of Cast Iron Micro-Specimens and the Metallography of Graphite Flakes," and "The Metallography of Inclusions in Cast Irons and Pig Irons." Both these latter papers are by Mr. H. Morrogh of the British Cast Iron Research Association.

* See *Metallurgia* 22, No. 131, pp 154-6.

Third Report of the Oxygen Sub-Committee

This Report, a lengthy summary of which is given elsewhere in this issue, was introduced by Dr. T. Swinden, chairman of the Oxygen Sub-Committee, and an interesting discussion followed.

Mr. Vernon Harbord expressed appreciation of the valuable work of the Sub-Committee in trying to determine by chemical methods the oxygen in steel, but it seemed to him that the question was not only one of chemical oxide determination, but also one of the distribution of the oxygen in the steel. Mr. R. Percival Smith spoke from the point of view of the steelmaker, and said there was one thing he wanted to know, namely: Would steelmakers within a measurable time have means at their disposal to determine the oxygen content of the steel on the stage before tapping? Dr. R. S. Sarjant wondered whether the Committee could give their attention to finding a quick method for the determination of gases. He had himself applied the Schenck method of determining the oxygen content from the rate of carbon drop. Those who were dealing with the matter from the point of view of works organisation would like to know what were the limits of error expected to be due to experimental method in the laboratory, and what were the so-called sampling errors, due to the method of taking the sample? Mr. D. A. Oliver expressed his admiration for the report, and considered that the methods developed would be of great value in the laboratory as a check on steelmaking processes which could be repeated. . . . It was increasingly important to aim at reproducing a state of affairs in repeated casts of the same steel. If some reproducible di-oxidisation procedure was followed through, it was evident that within certain practical limits, it was possible to achieve a high degree of uniformity. The application of the new methods to a more rigid regime in melting procedure, would result in a great stride forward in the quality of the product.

In replying, Dr. Swinden agreed with Mr. Harbord in emphasising the importance of the distribution of oxygen, as distinct from the total oxygen content. Mr. Smith had asked a very pertinent question: "Were we within measurable distance of the time when it would be possible to determine oxygen in steel before the bath was tapped?" That was the goal at which he himself was definitely aiming, and he thought that they were within measurable distance of doing it. There were possibilities of determining, within a reasonable time at least, the more reducible oxides, such as FeO and MnO. When this had been accomplished, he thought that a valuable tool would be placed in the hands of the steelmaker. Dr. Sarjant had extended the problem to a quick method of determining gases, assuming that oxygen was not present as a gas, and even that was debatable. In the vacuum fusion method the hydrogen and nitrogen were determined together with the oxygen. In correlating results between samples taken from the bath, the ingot, the billet and the bar, it was known that the hydrogen content did vary. According to experience so far obtained, it varied in one direction; it tended to be reduced as between the test sample cast from the bath right down to the bar. He would prefer the Committee to give a considered reply on the question of the error limits. It was particularly heartening to hear Mr. Oliver's contribution, and to know that the work which the Committee had done would already be regarded as of direct practical importance in controlling steel manufacture.

The Polishing of Cast-Iron Micro-Specimens and the Metallography of Graphite Flakes
The Metallography of Inclusions in Cast-Iron and Pig-Irons

These papers by Mr. H. Morrogh, of the British Cast Iron Research Association, lengthy abstracts of which

are published in the March, 1941, and December, 1940 issues, respectively, of this journal, created much discussion. Dr. J. E. Hurst welcomed the opportunity of speaking on these two papers as he had had the opportunity of seeing some of the author's work at first hand, and would like to congratulate him on the work he had done. The most important feature of the work was probably the systematic and organised way in which he had carried it out, but he was also to be congratulated on the systematic and organised way in which he had presented it in these papers. So far as cast iron metallurgy was concerned, the author had established a scientific method of studying the question of inclusions, and they would be regarded as standard papers for many years to come. In the paper on the polishing of cast-iron micro-specimens, he had been fascinated by two micrographs in which the author was able to disclose where the hypereutectoid and eutectoid graphite went to. People had talked very glibly in the past about hypereutectoid and eutectoid graphite, and might have surmised where it had finally deposited itself, but he did not think that they had ever before been shown so clearly exactly where the hypereutectoid graphite was to be found. In the other paper the author's work had brought out in a very striking manner the importance of the sulphur compounds, both manganese and iron, in determining the structural characteristics, at least of malleable cast iron, if not of ordinary grey iron; and a good many cast iron metallurgists were convinced that the importance and significance of those two constituents had not yet been exhausted.

Many other members contributed to the discussion of these papers, including Mr. T. Henry Turner, Mr. J. G. Pearce, Mr. Vernon Harbord, Mr. A. Allison, and Dr. Swinden. The President congratulated the author on, while still a young man, presenting papers of such importance. He was glad to think that young men were coming into the industry who, early in life, were offering such serious contributions to the solution of great problems. Owing to the lateness of the hour, he asked the author to reply to the discussion in writing.

The Corrosion of Copper and Some Copper Alloys in Atmospheres Highly Polluted with Coal Smoke

Results are given of corrosion tests made in railway tunnels for 40 months on materials that include arsenical copper, cupro-nickel, Everdur, and aluminium bronze sheets, and cadmium-bronze and tin-bronze wires. Most of these, although corroded about ten times as fast as would be expected in the open air, have, nevertheless, been found superior in life and long-term cost to ferrous materials, including stainless steel.

SOME exposure tests of sheet metals and protective coatings, which have been made in a railway tunnel, have been described elsewhere.[1] The behaviour of copper and its alloys in these tests was, in general, good, and showed some features that seemed worth a more detailed account than could be given in the general report on the tests. Other tests, in which wires of cadmium-bronze and tin-bronze have been in service in signal operation in tunnels, have also given results of interest.

In both tests the rapid building up of dense layers of corrosion product was noteworthy, and the nature of these products has now been investigated. The behaviour of aluminium bronze gave rise to some laboratory work on the selective corrosion of this material, and the results are given in a paper by Mr. S. C. Britton,* from which this article is abstracted.

The Exposure Tests

Tests of Sheets.—To assist in the design of ventilating equipment to handle the exhaust gases of steam locomotives, tests of a large number of metals and protective coatings were made in a ventilating shaft of the St. Pancras Tunnel of the London, Midland, and Scottish Railway. The arrangement and general results of these tests have been described elsewhere,[1] and it is now only necessary to give brief details.

Two types of test-piece were prepared from 14 S.W.G. sheet, which, for copper and its alloys, was hot-rolled. Curved sheets, each 1 ft. broad and forming a quadrant of a cylinder of 2-ft. radius, were arranged 12 ft. above the line of passage of locomotive chimneys. Other test-pieces, bent to give two 1-ft. squares, one horizontal and the other vertical, were placed so that the exhaust gases from the locomotive chimneys were deflected on to them by the curved plates. The passage of the gases over the angular plates was also assisted by a fan exhausting from the tunnel for discharge to the open air.

The deposit of soot and ash which fell upon the exposed specimens remained continually moist. A typical deposit remaining on 100 cm.^{2} of glass surface after exposure for 14 days contained the following matter, expressed in mgm.: water 1,590, tarry matter 2·7, other carbonaceous material 154, insoluble mineral matter (ash) 100, soluble sulphates (expressed as SO_3) 19, soluble chlorides (expressed as Cl) 9, soluble lime (expressed as CaO) 4·7, and soluble iron (expressed as Fe_2O_3) 14·3. The sulphur dioxide content of the atmosphere varied with the frequency of passage of trains, the range being between 2 and 9 p.m.

The total time of exposure was 3¼ years. During this period unprotected test-pieces of mild steel were completely destroyed by corrosion, and those of austenitic stainless steel, stainless iron, and aluminium were perforated at many places. The extent of the losses from the copper alloy specimens is shown, together with the compositions of the alloys, in Table I. Measurements were made both by micro-examination of sections of the sheets mounted in Bakelite and, after the corrosion product had been scraped away, by a ball-ended micrometer applied to portions of the test-pieces that had been measured before exposure. There were no pits, so that these methods gave a reasonable measure of damage. Some mechanical test results are given in the general report.[1]

Tests of Wires.—Galvanized steel wires used to operate railway signals have very short lives in tunnels used by steam trains, sometimes as little as six months. Experiments have therefore been made with two copper alloys which, when hard drawn, had the necessary mechanical properties. These were bronzes containing 2% of cadmium or tin. Wires consisting of seven 17-S.W.G. strands were

* *Jour. Inst. Metals*, April, 1941, **67**, pp. 119-133.

[1] S. C. Britton, *J. Inst. Civil Eng.*, 1941, **16**, 65.

TABLE I.

Specimen No.: Alloy:	12 (angle). Copper.	10 (angle). Everdur.	9B (curved). Everdur.	9 (angle). Cupro nickel.	11 (angle). Aluminium Bronze.	2B (curved). Aluminium Bronze.
Analysis (%).						
Copper	99·7	96·0	95·8	79·9	91·0	90·3
Nickel	—	—	—	19·9	—	—
Aluminium	—	—	—	—	8·6	9·1
Iron	—	—	—	—	0·3	0·5
Manganese	—	0·9	1·0	—	—	—
Silicon	—	2·8	3·0	—	—	—
Arsenic	0·19	—	—	—	—	—
Effects of Corrosion. Loss of Metal.	Uniform loss of thickness of 0·005-0·007 in.	Uniform loss of thickness of 0·005-0·007 in. with, in addition, intercrystalline penetration to a depth of 0·005 in. from each surface (Fig. 2).	Uniform loss of thickness of 0·005-0·007 in. with, in addition, intercrystalline penetration to a depth of 0·005 in. from each surface.	Uniform loss of thickness of 0·008-0·010 in.	Loss of thickness rather patchy, varying between 0·007 and 0·012 in. with, in addition, some intercrystalline penetration to a depth of 0·001 in. from each surface (Fig. 6).	The β phase in this alloy had been selectively corroded, copper-coloured residue being left, to a depth of 0·025 in. from each surface (Fig. 4).
Corrosion Product.	Adherent dense green layer 0·005 in. thick completely covering the metal.			Green layer, rather flaky in character and easily removed, some patches of the metal being bare.	Large patches (aggregating to about 30%) of the metal surface bare, and the remainder covered with a crumbly green product about 0·002 in. thick.	Upper side of specimens coated with fairly dense green product with the exception of a few patches, but underside had no continuous layer covering the metal

put into service in four tunnels of the London, Midland, and Scottish Railway in 1936. The wires were supported on pulleys at the side of the tunnel about 18 in. from the ground.

It became evident after a brief experience that although the wires were behaving well, the galvanized iron pulleys over which they ran were being corroded far faster than their neighbours carrying galvanized wires. A trial was therefore made of pulleys machined from a commercial Bakelite-fabric laminated sheet material, produced for service in the chemical industry. In Table II are shown the breaking loads of samples of the wire before and after use for 40 months in two tunnels. The test samples were taken from lengths between pulleys.

The wires had suffered rather more loss in strength where they had been rubbed on pulleys. Nevertheless, much of the wire was considered still serviceable after 40 months, and was permitted to remain. During this first 40 months of life, galvanized wires running parallel with the copper-alloy wires in Woodside Tunnel had to be replaced six times. Thus, in spite of the higher initial cost of the copper alloys, installation and renewal costs for a copper-alloy wire after 40 months were only one-third of those for galvanized wire. The Bakelite fabric pulleys appeared almost unchanged by their service.

Investigation of Corrosion Products and Discussion of Results

The corrosion products were scraped from the sheets after the deposit of soot, about a quarter of an inch thick, had been washed off, and were obtained from the wires by simply opening out the strands. Three methods of examination were used: observation of sections with the microscope, chemical analysis, and estimations of refractive index. The results of chemical analyses are given in Table III.

All the methods of examination indicate that the corrosion products consist of compact layers of basic sulphates and chlorides similar to those that appear to give so much protection to copper after it has been freely exposed out of doors. There is thus a hope that the rate of corrosion will be slower in further periods of exposure than it was during the initial period. It is noteworthy that, even during the test period, the least corroded sheets were those of copper and Everdur, to which the corrosion product adhered best, and that the interior of the wires, where the corrosion product was retained between the strands, was far better preserved than the exterior.

TABLE II.

Condition of Wire.	Breaking Loads of Complete Wire, tons.	
	2% Tin Bronze.	2% Cadmium Bronze
New	0·866	0·928
40 months' service in Haddon Tunnel	0·638, 0·637, 0·591 (Mean = 0·622)	0·582, 0·574, 0·489 (Mean = 0·548)
40 months' service in Woodside Tunnel	0·666, 0·694, 0·701 (Mean = 0·687)	0·628, 0·594, 0·585 (Mean = 0·602)

The small amount of nickel in the final corrosion product of cupro-nickel is no doubt due to the washing out of nickel salts, which as Vernon has shown,[5] become insoluble basic compounds only very slowly on exposure. Hudson[6] has found a similar effect out of doors. The selective solution of part of the corrosion product on this alloy probably accounts for its flaky nature, also observed by Hudson.[7]

TABLE III.—CHEMICAL ANALYSES OF CORROSION PRODUCTS.
(Figures, except those for basicity, represent percentages.)

Alloy:	Copper.	Everdur 11.	Everdur 9B.	Cupro-nickel.	Aluminium Bronze 11.	Aluminium Bronze 2B.	Copper-Cadmium.	Copper-Tin.	Copper-Tin.	Copper-Cadmium.
Tunnel:	St. Pancras.	St. Pancras.	St. Pancras.	St. Pancras.	St. Pancras.	St. Pancras.	Haddon.	Haddon.	Woodside.	Woodside.
Copper (Cu)	54·9	48·6	49·8	52·5	45·0	45·1	50·9	51·3	49·3	—
Iron Oxide (Fe_2O_3)	1·7	0·8	—	1·7	3·1	0·2	—	—	—	—
Alumina (Al_2O_3)	2·6	2·0	—	1·7	10·4	10·6	—	—	—	—
Sulphate (SO_4)	4·5	14·3	5·0	3·9	11·7	6·9	23·6	24·5	7·4	—
Chlorine (Cl)	13·7	7·4	14·3	14·2	14·2	13·7	3·2	2·8	19·2	13·0
Insoluble Matter	0·5	6·8	7·0	0·7	0·8	0·4	—	—	—	—
Other Radicals	—	Silica (SiO_2) (in insoluble matter) 4·7 Manganese Oxide (MnO) 0·3	5·4 —	Nickel Oxide (NiO) 0·4	—	—	—	—	—	—
Calculated Analysis.										
Basicity[8] of copper chloride and sulphate	2·59	2·00	2·07	2·41	1·18	1·66	1·75	1·75	1·22	—
Basic copper chloride	75·7	35·1	67·7	74·3	50·3	57·5	13·9	12·0	68·9	—
Basic copper sulphate	18·6	53·5	18·8	16·1	33·7	23·3	81·4	84·0	21·5	—
Ash and soot	4·8	4·9	—	4·1	3·9	0·6	—	—	—	—
Other matter	—	SiO_2 4·7 MnO 0·4	SiO_2 5·4	NiO 0·4	Al_2O_3 10·4	Al_2O_3 10·6	—	—	—	—
Undetermined	0·2	1·4	8·1 incl. ash, soot, and MnO	5·1	1·7	8·0	4·7 (including ash, soot, Cd, and Sn)	4·0	9·6	—

[8] Basicity is shown as the value of x in the formulæ $CuCl_2.xCu(OH)_2$ and $CuSO_4.xCu(OH)_2$.

[5] W. H. J. Vernon, *J. Inst. Metals*, 1932, **48**, 121. [6] J. C. Hudson, *J. Inst. Metals*, 1930, **44**, 409. [7] J. C. Hudson, *Trans. Faraday Soc.*, 1929, **25**, 199.

The large quantities of chloride found in the corrosion products are remarkable, since Vernon and Whitby have always found that sulphates predominate in the corrosion products occurring on copper remote from marine influence. The deposit collected on glass in St. Pancras Tunnel contained about half as much chloride as sulphate, and was therefore not unduly rich in chlorides when compared with deposits in inland towns, as shown in the Annual Reports of the Department of Scientific and Industrial Research on "The Investigation of Atmospheric Pollution." There is, of course, chlorine in coal, and it has been calculated[8] that a locomotive firebox atmosphere might contain 0·1 to 0·01% by volume of hydrochloric acid. The tunnel chlorides probably came from this source.

Copper is normally corroded more rapidly by chlorides than by sulphates, either in neutral or in acid solution. Vernon[9] showed by laboratory experiments that an atmosphere of 50% relative humidity containing 0·01% of hydrochloric acid corroded copper far faster than a similar atmosphere containing 1·0% of sulphur dioxide, and as fast as one containing both 0·01% hydrochloric acid and 1·0% sulphur dioxide. The product formed was cuprous chloride. Further, copper sulphate absorbs hydrochloric acid. It is therefore surprising in view of the presence of chlorides in the atmosphere, that all atmospheric corrosion products of copper do not contain substantial amounts of chloride. It seems likely that the corrosion process in the tunnels, and possibly in atmospheres rich in sea-salt, follows a rather different course from that taken inland in the open air.

The corrosion products formed in the tunnels resemble in many respects those found by Bengough and May[10] on copper corroded by neutral sodium chloride solutions. There is the same large quantity of basic salt, some normal salt, and the layers of copper or of cuprite on the metal surface. Probably the continual wetness of the metal exposed in the tunnels produces the effect of complete immersion in liquid. The general action is probably an electrochemical process developed from superficial variations either inherent in the metals, as for the intercrystalline penetration observed, or due to drops of moisture or particles of soot resting on the surface. This results in the formation of normal copper chloride and sulphates at anodic points and the discharge, at first, mainly of hydrogen ions at the cathodic points, producing there some local reduction in acidity. If conditions are not too acid the mixture of anodic and cathodic products produces some basic sulphate and chloride. Chlorides of copper that escape this form of "fixation" may still be held as insoluble products by reaction with oxygen, as indicated by Bengough and May, and the production of cuprite is part of this process. The copper deposits observed on the surface of the corroded metals are no doubt due to secondary changes. Probably, as suggested by Bengough and May, in corrosion by sodium chloride solution the copper is deposited in cupric chloride concentration cells.

The slightly soluble cuprous chloride, expected as a primary corrosion product, will not be readily washed away, and much of it will be retained at the metal surface, giving the secondary changes a chance to take place there. Sulphates that escape immediate precipitation by cathodic alkali may easily be lost, for, if by hydrolysis they acquire a basic character, such a change must take place in solution and the product will not be likely to adhere to the metal. It is not surprising, on this view, that chlorides predominate in the corrosion products from the tunnels.

In the open air, the solutions come into contact with the metal only intermittently and are much less concentrated than those in the tunnels. There is thus less chance of the initiation of corrosion by dissolved sulphates and chlorides. Gaseous impurities such as hydrogen sulphide, possibly because they penetrate the primary oxide film and adhere to the metal more effectively than ions in dilute solutions, may play a more important part. This accords with the finding of Vernon and Whitby that the films initially formed on copper in the open air are a mixture of oxide and sulphide of copper with soot. Certainly, the slow rate of accumulation of sulphates and chlorides is not due to their removal in rain-water, since shelter from the rain retards the development of green deposits. Vernon and Whitby suggest that the green layers formed later on are, in some part, due to the oxidation of the first-formed sulphide deposit. Such a method of formation explains why chlorides are so inconspicuous in most of the products examined, in spite of their corrosive nature, and of their widespread occurrence in rain.

In locations near the sea or exposed directly to sea-breezes, the concentration of chloride in the rain falling on to the metal may be sufficient to initiate electrochemical corrosion of the form suggested for tunnel conditions. It is noteworthy that the higher-chloride patinas examined by Vernon and Whitby are those that are believed to have been formed most rapidly, and that Hudson[11] also noticed a more rapid formation of green deposit where exposure to chlorides was greatest.

The Corrosion of Aluminium Bronze

Atmospheric Corrosion.—Of the two samples of aluminium bronze exposed in St. Pancras Tunnel, the alloy 2B with 9·1% of aluminium had a distinct ($\alpha + \beta$) structure, but alloy 11 with 8·6% of aluminium had only a few streaks of the ($\alpha + \delta$) eutectoid scattered through the α constituent. The difference in resistance to corrosion was remarkable. After exposure, the β constituent of the alloy 2B had been replaced by a copper residue for two-thirds of the thickness of the sheet, the α phase being unattacked, whereas during the same time the alloy 11 suffered superficial damage only.

The formation of copper in the alloy 2 B appears to have been due to the selective removal of aluminium, for there is no gap between copper and unchanged metal such as might be expected if the copper resulted from a re-deposition process. The corrosion of alloy 11 was intercrystalline, possibly following traces of a second constituent. A copper residue has been left in the track of the attack, and appears as a general layer on the surface. This resembles the deposit formed on copper, and seems more likely to be the result of re-deposition.

The corrosion of aluminium bronze in acids has been investigated by Musatti and Dainelli,[12] who found that for an alloy containing 10% of aluminium, the production of a fine-grained structure considerably accelerated corrosion by hydrochloric or sulphuric acid, and that the ($x + \delta$) eutectoid could be selectively dissolved. McKay and Worthington[13] reported the appearance of copper deposits at the water-line on aluminium bronzes of unspecified composition after partial immersion in acids, and the selective corrosion of two-phase alloys, both of which they describe as "de-aluminification." (The present author suggests that if a special term be required, "coppering" is easier to say and is just as accurate a representation of the occurrence.) Corrosion tests by the American Society for Testing Materials[14] have shown that duplex alloys may be more rapidly corroded than single-phase alloys in salt water. The selective corrosion of aluminium bronzes in steam atmospheres has also been reported.[15, 17].

Laboratory Tests.—The various reports cited above, and the results obtained in the tunnel exposure, while agreeing in the general tendency that a continuous second phase favours increased rate of penetration of corrosion, appear

(*Continued on page* 34.)

[8] O. F. Hudson, T. M. Herbert, F. E. Ball, and E. H. Bucknall, *J. Inst. Metals*, 1929, **42**, 246.
[9] W. H. J. Vernon, *Trans. Faraday Soc.*, 1931, **27**, 267.
[10] G. D. Bengough and R. May, *J. Inst. Metals*, 1924, **32**, 109.
[11] J. C. Hudson, *Trans. Faraday Soc.*, 1929, **25**, 195.
[12] I. Musatti and L. Dainelli, *Alluminio*, 1935, **4**, 51.
[13] R. J. McKay, and R. Worthington, "The Corrosion-Resistance of Metals and Alloys." New York: **1936**, pp. 439 and 444.
[14] Reports of Committee B-3, *Proc. Amer. Soc. Test. Mat.*, 1934, **34** (I), 221: 1935, **35** (I), 141.
[15] "Aluminium Bronze," Copper Development Association: **1938**, p. 68.
[17] A. P. C. Hallowes and E. Voce, *Brit. Non-ferrous Metals Res. Assoc., Research Rep.*, **1940**.

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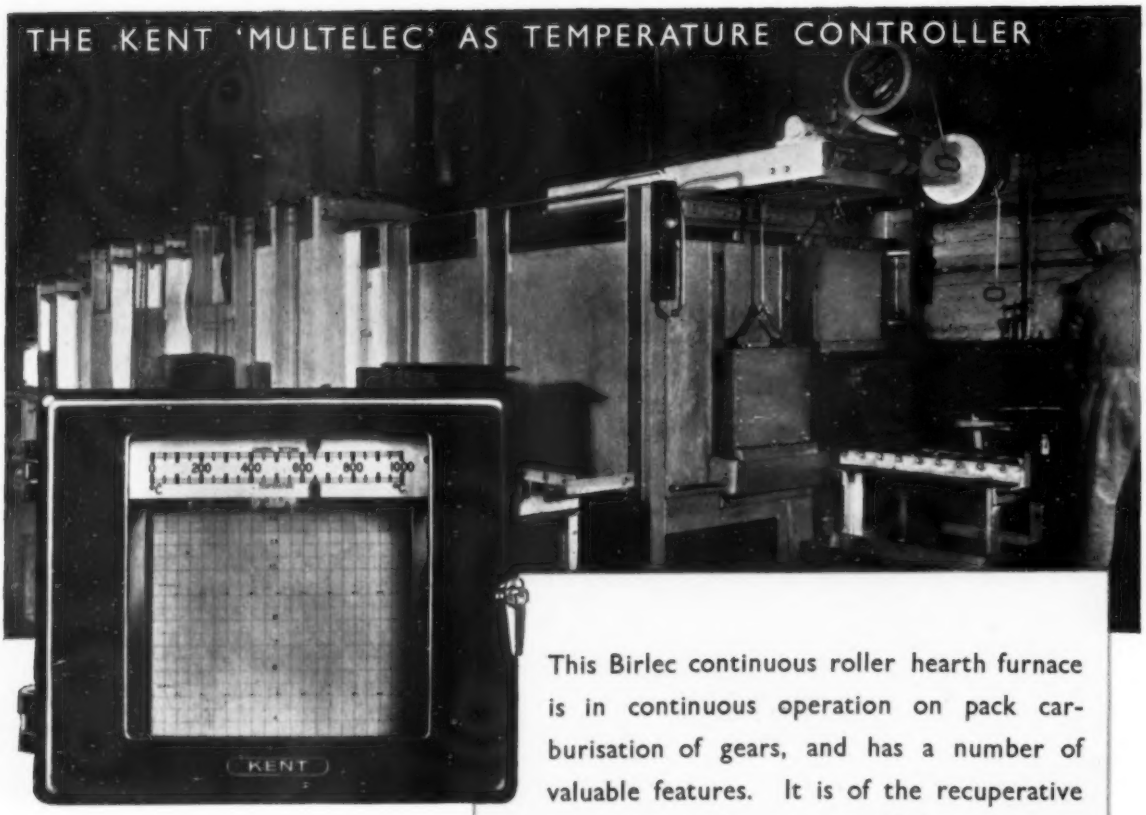

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GEORGE KENT

HEAT TREATMENT
PROCESSES — PRACTICE — PLANT

May, 1941 METALLURGIA Vol. XXIV, No. 139

ELSEWHERE in this issue reference is made to the importance of design in making the most economical use of materials, but this is only one of the factors that contribute to economy of materials under present service conditions; probably the most important contribution results from the addition of alloying elements to both ferrous and non-ferrous metals. Practically all base metals are weak in their pure state, but, by the addition of suitable elements, their properties are vastly improved; the presence of carbon in iron, for instance, to form steel produces a remarkable change in properties, while further changes of an outstanding character are obtained as the result of adding small quantities of other elements to a carbon steel. The range and variety of ferrous alloys produced to meet modern service conditions are too great even to review here, but the majority produce their best mechanical properties when *in the hardened and tempered condition.*

The same is true of other metals. Aluminium, for instance, which is so necessary at the present time in aircraft construction, is dependant for its high mechanical properties on the addition of small percentages of other elements. Probably the most interesting of these alloys are those which undergo age-hardening. The essential condition that an alloy shall be susceptible to age-hardening is that it contains a constituent which can be brought into solid solution at a high temperature, but has a solubility which falls rapidly with falling temperature. The constituent is retained in solid solution by quenching, and is released, either spontaneously at atmospheric temperature, or on heating to a moderate degree. Many of these alloys, *in the heat-treated condition*, are comparable in mechanical strength with structural steels.

In the majority of cases the improved mechanical properties obtained from ferrous and non-ferrous alloys are the result of some form of heat-treatment, and to a large extent the condition of the structure of an alloy imparted by heat-treatment is dependant upon the service to which it is to be subjected. Modifications in heat-treatment affect its mechanical properties: thus it is possible to produce a range from the same alloy in which the properties differ, and heat-treatment can be regarded as another factor in the economical use of materials. The importance of heating and cooling the alloy to produce the desired structure has resulted in much research work which has been of great assistance to industry, not only in reducing the sizes of components and yet maintaining their strength, but in obtaining structures satisfactory for particular conditions of service. The structural changes in steel, for instance, have been investigated over a period of many years.

In more recent years increasing attention has been given to heat-treatment, and a new method of investigating steel has been developed in which the steel is heated to such a temperature that it is entirely in the condition of homogeneous austenite, from which it is cooled rapidly to some predetermined temperature, allowing the transformation to proceed isothermally, and then quenching rapidly. Davenport* reviewed the investigations on the isothermal transformation of austenite which had been in progress for 10 years, and which have altered so radically the theory of the heat-treatment of steels.

In the study of any given cooling rate, time and temperature are changing simultaneously, so that it is impossible to evaluate the separate influence of either; the constant temperature or isothermal transformation of austenite was, therefore, investigated. The observations are summarised in the so-called "S" curve diagram, which indicates the time required for the breakdown of austenite at any constant temperature below the equilibrium transformation range. It appears that these investigations have contributed to an improved understanding of the heat-treatment of steel in at least four major ways.

They have provided us with a new, more comprehensive picture of the transformation of austenite, which, in turn, furnishes a new basis for a broad, general philosophy of heat-treatment. By thinking in terms of the "S" curve, many facts, long recognised but only vaguely correlated, fall into proper place in a consistent picture of the whole subject of heat-treatment.

They have demonstrated the outstanding influence of the actual temperature of transformation on the character and properties of the several structures possible in a given steel, and on the essentially continuous variation producible in any single category of structures, such as the lamellar series (pearlite), or the acicular series (bainite or martensite).

They have permitted us to evaluate the influence of alloying elements in micro-structure, mechanical properties, depth of hardening, and on many other criteria employed to judge the results of heat-treatment. Chemical composition of the austenite, prior to cooling, profoundly influences the shape and location of the "S" curve, hence the response to a given heat-treatment and it is in this field that isothermal transformation studies are of practical value in enabling us to account for the specific effects produced by an element or combination of elements in solution in the austenite.

They have contributed to a rational explanation of the influence of coarser austenite grain size, which displaces the "S" curve in much the same manner as an alloying element. As the grain size increases, the Ar^1 region of the "S" curve moves significantly to the right, reflecting the increased reluctance of the steel to transform. This accounts for the long-recognised fact that higher heating temperatures, which produce coarser austenite grains, give rise to deeper hardening.

Thus, the isothermal transformation rate is fundamental, and any factor or set of circumstances which influences it, and affects the shape and location of the "S" curve, will exert a corresponding influence on the response of the steel to heat-treatment. Investigation of the influence of alloying elements indicated that, with the exception of cobalt, almost any element which can be put into true solid solution in austenite retards the transformation of that austenite when cooled below its temperature range of stable existence. Thus, for a given rate of cooling of austenite, the alloy steel transforms at lower temperatures, and hence forms harder, stronger structures than does a carbon steel comparably treated.

Much research work has been carried out in recent years on the heat-treatment of aluminium alloys, and a review of the present technique of heat-treatment which has been developed and applied to wrought aluminium alloys is given by Mr. Towns Robinson in this issue, and attention is particularly directed to the reference on the study of the problem of internal stresses and of the possibility of their determination in a known and measurable quantity. Increasing knowledge of heat-treatment and its application in practice will further increase the service possible from both ferrous and non-ferrous alloys, and contribute to the economical use of materials.

* Transactions of American Society of Metals, Dec., 1939, pp. 837-886.

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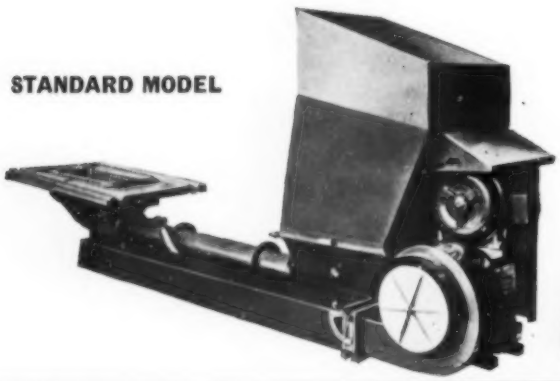

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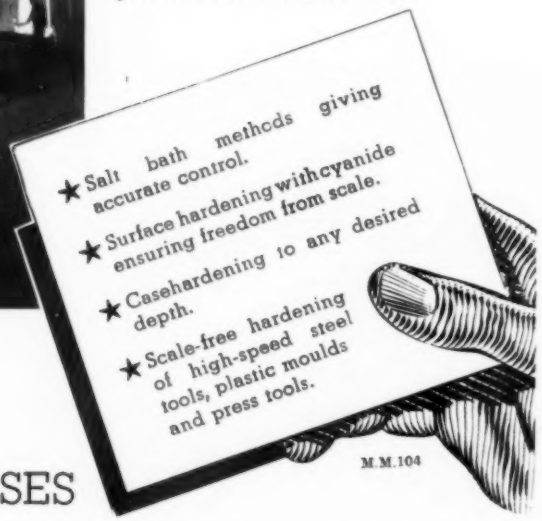
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HEAT TREATMENT PROCESSES

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A Review of the Present Technique of Heat-Treatment as Applied to Wrought Aluminium Alloys

By J. Towns Robinson

Technical Superintendent, High Duty Alloys Ltd.

Considerable progress has been made in the development of heat-treatment technique applied to aluminium alloys. In this review of the subject the factors governing successful heat-treatment practice are discussed, and attention directed to improved plant and equipment, the interpretation of micro-structures, and the importance of the effects of internal stresses. Brief reference is made to the development of a special technique by which internal stresses can be accurately estimated.

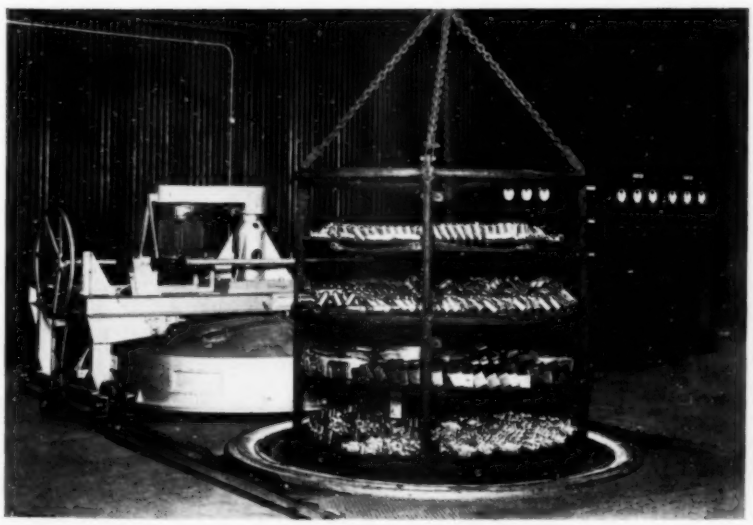
IN the past, a great deal has been written on the thermic treatment of aluminium alloys, and there is no doubt that rapid progress was made on what was really a new branch of modern science. A high standard of quality was successfully achieved, even though it was necessary to exercise great care and accuracy due to the inherent characteristics of the material and the specific temperatures employed, and the fact that these temperatures were very near to the fusion point of the eutectic alloy and subsequent dangers of overheating.

This stage of advancement, however, was imperative both for the successful operation and future progress of aluminium alloys, and was no doubt instrumental in their consolidation apart from their characteristic lightness in engineering development. It is not proposed here to deal with the theoretical side which is by now well known, although the evidence is perhaps by no means positively conclusive, and still occupies the efforts of the research worker.

In comparatively recent times a further stage has been entered upon embodying an entirely different aspect towards the physical properties required by the process of heat-treatment, and here again progress has been both rapid and marked. The old fundamental principles governing heat-treatment were convened to obtain the highest possible mechanical properties consistent to each particular type of alloy designed by its own chemical characteristics. This was done quite irrespective of the function which the component was called upon to operate under service conditions and in a great number of instances these conditions were of a most exacting nature with a complexity of varying stress conditions, some of which were even totally unknown. Scientific and research investigation carried out over the last few years, both by the metallurgist and the experimental engineer, have brought the fact to light that a large number of failures can be attributed to the physical condition of the component brought about by unsuitable heat-treatment. The fact must, however, be stressed that this should not be interpreted as incorrect heat-treatment as such, but to the fact that certain physical properties or, one might say, characteristics of the alloy, have been sacrificed for maximum mechanical properties usually stated in terms of tensile strength. The technique of heat-treatment adopted in the fabrication of light alloys cannot be to blame in this respect, because, in many instances, the designer has been completely unaware of the nature of certain complex stresses met with under service conditions until they have been ascertained by failure and/or by experiments. This has not been an easy task, and, even at the present time, a complete understanding of stress problems, their nature, intensity and directional advantages or disadvantages is only in its initial stages, and large fields are yet to be explored introducing intensive research into this fascinating subject.

The importance of the correct physical condition of any component brought about by heat-treatment, not only applies to the highly-stressed parts of an aero engine, but equally so to the successful functioning of any such part

Pit-type solution-treatment electric air-circulation furnaces showing method of charging. A high air speed is achieved, of the order of 20-30 ft. per sec. with a full load, and temperature controlled within ±2° C. Note the panel for controlling the treatment in these furnaces.



Gas-fired low-temperature ageing furnace. Combustion takes place in a separate chamber, and hot air is circulated in the working chamber.

in, say, a more lowly stressed car or lorry engine. Take, for example, the average motor-car piston, and we find not very long ago maximum Brinell hardness was called for, apparently under the supposition that this condition was imperative for the best frictional values. "Unaccountable" failures occurred owing to seizure and ultimate fracture which, upon investigation, proved to be directly attributable to existing hardness, and it was ultimately found that a considerable reduction in hardness gave greatly-improved performances and even frictional values. Grave dangers of failure must have frequently been risked on such parts during the process of softening under operating conditions, due to the heat stresses set up through this transition period.

Similar conditions were also encountered with the aero engine piston where maximum strength and hardness were often demanded as criterions of quality, and the seriousness of failures can be well imagined. It can be rightly said that aero engine pistons are now successfully operating under the most highly-stressed conditions with a hardness and a physical condition which would not even have been contemplated only a few years ago.

Main Factors Governing Successful Heat-Treatment.

The three main features governing the successful heat-treatment of aluminium alloys can be broadly classified as follows:

1. Improved plant and equipment, furnaces, etc
2. Greater knowledge of the interpretation of the microstructure, to ensure uniform dispersion of the hardening constituents, particle size, and estimation of temperature control.
3. The importance of the effects of internal stresses imposed by quenching plus the super-imposed service stresses both at atmospheric and elevated temperatures.

The application of these principles, of course, only becomes operative when the quality of the material is of a high standard, and its chemical composition known and controlled to within fine limits. This is also to be accompanied by suitable breakdown of the original cast structure, whether working from cast ingot or wrought stock, by adequate working such as forging or pressing and imparting to the final component the preferential grain flow to produce the optimum results in the desired plane after heat-treatment.

Development of Equipment

Great strides have recently been made in the development of suitable equipment such as furnaces which have become much more easily and accurately controlled. The introduction of automatic control and high-speed efficiency fans with subsequent increased air circulation have produced practically ideal conditions of temperature control and heat distribution. Here again, a greater knowledge and study of refractory materials has greatly helped to make this possible, indeed, the whole subject has been put on the basis of a laboratory problem. The advent of "zoning" in furnace construction—the division of heating elements into separate circuits ensures more uniformity of heat distribution and checks any variation due to unequal loading. At the temperatures required for the heat-treamtent of aluminium alloys, usually in the range of 480° to 530° C., it is a practice to employ convexion and not radiation as heat flow which guarantees greater uniformity. It is necessary to see that complete circulation exists round each individual item of the charge, and that the circulation is not impeded by both the mass and distribution of the load.

The molten salt bath, as a means of heating, gave excellent service during a period when the "air furnace" was in its early stages of development for the lower temperatures for aluminium alloys and difficulties were being experienced in obtaining uniformity of heating at these temperatures. The salt bath has been superseded by the "air furnace" for large-load capacity demanded by present production, but is still an extremely useful and efficient heating medium, and can be very accurately controlled. To assess on the economic basis the respective merits of the various types of "fuelling"—i.e., gas, electricity and oil—is somewhat difficult, because the local conditions regarding both the availability and cost is naturally a deciding factor.

A systematic checking of furnaces for temperature uniformity, both after installation and at frequent intervals, at a number of positions in the furnace is absolutely essential, and the same procedure is necessary when running under full load. Valuable information can thus be obtained and data compiled by a careful survey of these conditions which results in greater economy of running, increased production and ensures a high standard of quality of the heat-treated products.

Apart from the actual furnace construction the various equipment accessories, such as automatic handling gear, charging trolleys and racks, to give both ease and rapidity in removing the charge from the furnace to the quenching medium, have reached a stage of high mechanical efficiency.

Finally, but by no means the least important, is the system of pyrometric control by which the furnace is governed, and is a means of ascertaining that the furnace is correctly and accurately operating, and the very best instruments should be installed. Again, considerable progress has been made by the scientific instrument maker

Fig. 1.—Micro-structure of forged bar in Hiduminium R R 56 solution treated at 530° C, quenched and hardened. X 100. Standard practice.

Fig. 2.—As in Fig. 1, but solution treated at 545° C. X 100. Note the incipient fusion of the eutectic constituents and grain boundary cracking.

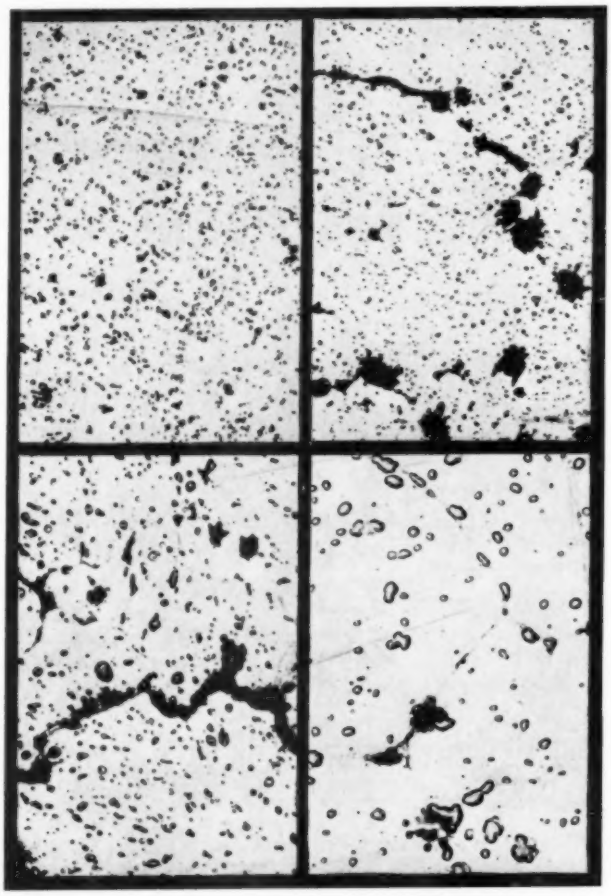


Fig. 3.—As in Fig. 1, but solution treated at 560° C. X 100. Note the severe intercrystalline cracking and the intracrystalline pools of liquated eutectic.

Fig. 4.—Similar forged-bar solution treated at 545° C., as in Fig. 2, but at larger magnification. X 500.

in producing both robust and supersensitive instruments which are the most vital part of furnace equipment. The pyrometric temperature control and recording system has become a highly scientific art, and the real nucleus of the heat-treatment plant.

Interpretation of Micro-Structure

A thorough knowledge and study of the interpretation of the micro-structure of the material cannot be too highly stressed, as by this means a fairly accurate estimation of the temperature to which the alloy has been subjected can be truly assessed. For instance, if slight overheating has taken place, during solution treatment, the mechanical properties are practically unaffected, but a careful study of the micro-structure at higher magnifications provides an indication of the extent to which eutectic liquation has taken place, and the temperature can thus be determined to within a few degrees. In the case of overheating to any serious extent, then the mechanical properties are immediately affected, but here, again, the micro-structure produces irrefutable evidence. An investigation of the influence of overheating during heat-treatment on the mechanical properties and micro-structure of forged material in Hiduminium R R 56 alloy produced some interesting features and very valuable information. On this material, correctly heat-treated at a temperature of 530° C., the standard mechanical properties were obtained with a typical well-defined micro-structure. When the same material was subjected to overheating at temperatures of 545° C. and 560° C. characteristic changes in the mechanical properties and micro-structure were immediately evidenced. Under low power at 100 diameters magnification, the alloy when heated to 545° C. gave the following characteristics.

(*a*) Intarcrystalline cracking.
(*b*) Pinholes.
(*c*) Slight spheroidisation.

At higher magnifications of 500 diameters, films of liquated eutectic can be observed at the grain boundaries. In the case of material overheated to 560° C. the following features are visible at 100 diameters magnification.

(*a*) Severe intercrystalline cracking.
(*b*) Large pinholes.
(*c*) Coalescence of constituent particles.
(*d*) Intracrystalline pools of liquated eutectic.

Examination at higher magnifications provides an indication of the extent to which eutectic liquation has progressed. As stated above, slight overheating does not necessarily effect the mechanical properties, but once the limiting temperature is reached, and definite overheating takes place, the first effect is a serious loss in elongation or ductility, which in the case of the alloy under discussion was immediately reduced from 12% elongation to the region of 1 to 2%, with long soaking, however, as encountered during production heat-treatment, a serious decrease both in the 0·1% proof stress and ultimate tensile strength is immediately apparent.

The effects upon mechanical properties of forged bar in Hiduminium R R 56 alloy after solution treatment at various temperatures, followed by the standard artificial ageing at 170° C. will be seen in the following table:

0·1% proof stress. Tons per sq. in.	Ultimate stress. Tons per sq. in.	Elongation. % on 2 in.	Brinell Hardness.
	Solution Treated at 530° C.		
22·00	28·90	12·0	138
	Solution Treated at 545° C.		
23·00	27·50	2·0	138
	Solution Treated at 560° C.		
22·5	26·50	1·5	114

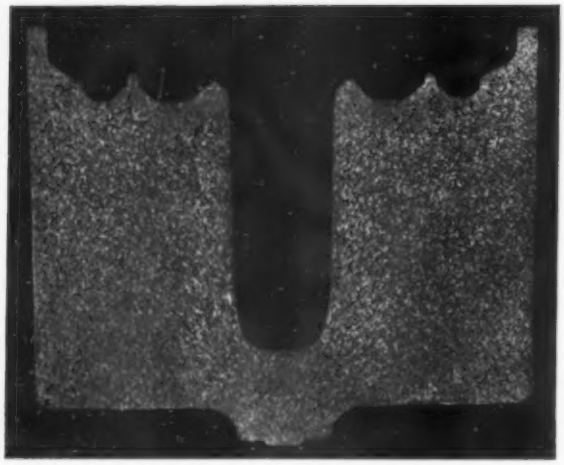
Effects of Internal Stresses

One of the most advanced stages in the technique of heat-treatment of aluminium alloys is the study of the problem of internal stresses which at the present time is the subject of investigation and research. The presence of internal stress in components which have been quenched from the solution temperature has, of course, been well known for a long time, but the tremendous difficulties experienced in determining it in a known and measurable quantity, and further, its subsequent effects under service conditions, have, of necessity, rendered progress slow. Both aspects of this problem demand the closest possible co-operation of the engineer and the scientist, and it would not be difficult to prophesy the value which will be gained by the ultimate solution and control of this subject. The question of constructional and operative stresses to the designer is one of some complexity which calls for experienced calculation and experimental work, therefore, with the addition of practically unknown stresses present in the component part, the huge task can well be imagined.

Half-section of an automobile piston pressing after etching, in Hiduminium R R 59, showing characteristic grain flow after heat-treatment.

Various methods have been evolved for the determination of internal stress chiefly of a mechanical nature, and comprising the cutting up of the component either into sections or by the insertion of "pins," and taking very accurate dimensional measurement both before and after cutting up, and although some of these methods have given reasonable information, their extreme accuracy is problematic.

Stress determination has been investigated by means of X-ray crystallography for some time, and has been the subject of intensive research in the laboratories of my company. As a result of the development of a special technique by Dr. Frommer, of our Research staff, the stage has now been reached when internal stresses in specially-prepared test material can be accurately estimated, and no difficulty is anticipated in the application of this method to actual component parts. A programme of research on components, such as aero-engine pistons, is now in progress, and it is anticipated that the results will produce some extremely valuable data, relative to the various methods of quenching, both to control and impose internal stresses in such a manner that they will assist the service working stresses, and not act in opposition to them, which undoubtedly happens when dealing with a complexity of unknown stresses. Future progress is envisaged by this method in adopting it for the determination of stresses both at elevated temperatures, and under stress loading conditions at these temperatures which will represent actual working or service conditions. Also, by this means, it will be possible to estimate the thermal stresses and even component parts, say, in an engine under actual running conditions.



Half section of an aero-engine piston pressing after etching, in R R 59, showing uniform crystal grain size and flow after heat-treatment.

Having described the latest developments for the determination of internal stresses in heat-treated components, it is of interest to briefly consider the factors which influence and control these stresses. When aluminium alloys are quenched from their solution treatment temperature into a media—usually water or oil—a rapid change in temperature takes place with the formation of thermal stresses, and these giving way in turn to residual internal stresses of converse character. The influencing factors are therefore, (*a*) mass of metal and shape of the component, (*b*) the quenching medium, and (*c*) the temperature of the quenching medium.

It is obvious, therefore, that the greater the mass of metal, plus changes in its shape or dimensions, the greater will be the thermal gradient set up resulting finally in greater residual stresses. It will also be seen that the shape and change in dimension of the quenched part effect the order of distribution of the stresses, some being in tension and others in compression and varying in respective layers from the surface of the metal inwards. It is important, therefore, to consider the final machine size of the part in relation to the stage at which it is qnenched during heat-treatment, otherwise the removal of large masses of metal during machining will result in unbalanced stresses of a detrimental nature. The minimum of metal should therefore be removed by machining after quenching, and so preserve the compressive stresses at the surface of the metal.

Finally, it must be remembered that although both the quenching media and its temperature influence the degree of internal stress, the resultant mechanical properties are dependent on the effectiveness of the quench. The slowing down of the rate of cooling or severity of the quench greatly relieves the amount of stress, and can be accomplished either by quenching in a hot medium such as boiling water, or by delaying the temperature at the moment of the quench to some degrees below that of the true solution treatment temperature. In the latter method, whilst the stress is relieved, it results in incomplete solution of the hardening constituents. Both these methods result in lower hardness and tensile strength, but usually improves the elongation or ductility of the final product, and this very often makes all the difference between success and failure of the component in service.

From this brief review it will be seen that considerable progress has been made in the knowledge of heat-treatment technique as applied to aluminium alloys, much research is still necessary, however, and large fields require to be explored to supply further aid to advancement and progress of aluminium alloys in general engineering practice.

Carburising with Gaseous Media

By F. Collins

The history, basic principles and developments of gaseous carburising are reviewed. Differences between gas and pack methods are discussed; reference is made to cost and to operating problems and the superiority of the method over pack carburising is explained. Brief reference is made to the selection of suitable furnaces, and to development trends of the process.

THE method of effecting carburisation by the introduction of a gas or fluid into the carburising chamber is not new; it was developed about the middle of the 19th century, but its application on a commercial scale is the result of modern research. The most important initial contributions on this subject were made by Frederico Giolitti between 1908 and 1912, when he published his researches on carburising. His book, *Cementation of Iron and Steel*, published in 1912, detailed the known facts, and made clear the underlying principles of the process.

The original principle of gas carburising, according to Giolitti, was based on the idea of diluting the carburising vapours of oils with an inert gas which would act as a vehicle for the carburising gases, carrying them into the cementation chamber, and preventing the formation of carbon deposits by their decomposition at the high temperature of cementation.

During the last few years the commercial application of gas carburising has made rapid progress in the United States, but, for some unaccountable reason, very little headway has been made in this country; it is significant however, that a batch-type furnace, using an oil to provide the required gas, is shortly to be put into operation, while a furnace of the continuous type has been in operation in this country for some considerable time.

Pack Carburising

Many engineers and heat-treaters believe that in the pack-carburising process the steel absorbs carbon as a result of direct contact with carbon particles in the carburising compound. But if carbon enrichment occurred only at the areas of contact, it will be appreciated that only spots of the surface would receive carbon enrichment and carburisation would lack uniformity; as is well known, this does not happen, because in this process carburisation is effected by carbon monoxide formed from the compound, and carbon absorption takes place over the entire surfaces surrounded by the compound. Pack carburising, therefore, is fundamentally gaseous in principle. In fact, each box containing work and compound is a small carburising unit, and the compound reacts in various ways to produce the necessary amount of gas to effect the phenomenon of carburisation.

The simplicity with which steel absorbs carbon while in a carburising compound, together with the fact that the operation is gaseous, would appear to indicate that by placing the part in a suitable container and merely passing over any carburising gas would be an easy and quite effective manner of carburising; but correct carburising cannot be achieved by such simple means.

The Chemistry of Pack and Gas Carburising

The method of carbon absorption is not the same in pack and gas carburising, and it is necessary to appreciate the difference between the two processes.

Pack Carburising: In this process the solid carbon of the compound reacts with the air in the box to form carbon monoxide.

$$2\,C + CO \longrightarrow 2\,CO.$$

The surface of the steel reacts with this gas to form carbide of iron—

$$2\,CO + 3\,Fe \longrightarrow Fe_3\,C. + CO_2$$

It is in fact necessary to have an energiser present in the carburising compound to enhance the richness of the carbon monoxide. Barium and sodium carbonates are generally used for this purpose. Sodium carbonate slowly reacts as follows:

$$Na_2\,CO_3 + C \longrightarrow Na_2O + 2\,CO.$$

In this way energisers tend to take up the CO_2, and thus raise the carbon monoxide content of the gas.

Gas Carburising: It was at first thought that carbon monoxide was the chief agent in gas carburising, but later investigations proved this belief to be erroneous, but this gas is used extensively as a diluent for hydrocarbons which provide the media for gas carburising. Hydrocarbons are combinations of carbon and hydrogen which constitute a large body of organic compounds. Those principally used in gas carburising are methane, propane and butane. At first it was believed that carbon monoxide was the principal agent in gas carburising; in later years, however the results of research proved otherwise, but carbon monoxide is now used as a diluent for richer hydrocarbons. The main gears used in gas carburising are:

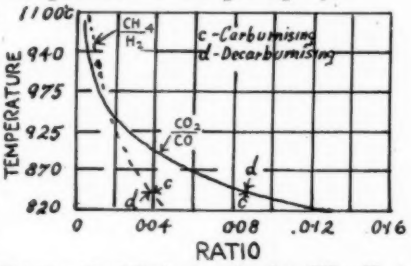


Fig. 1.—Equilibrium ratios for CH_4—H_2 + CO_2—CO reactions.
(Pring and Fairlee.)

Carburising.	Decarburising.	Neutral.
Methane, CH_4	Carbon dioxide, CO_2	Hydrogen, H
Ethane, C_2H_6	Water vapour, H_2O	Nitrogen, N
Propane, C_3H_8		
Butane, C_4H_{10}		
Carbon monoxide, CO		

The reactions effecting carburisation in gas carburising are

$$2\,CO \longrightarrow CO_2 + C.$$
$$C + 3\,Fe \longrightarrow Fe_3C$$
$$CH_4 \longrightarrow C + 2H_2$$
$$CH_4 + 3Fe \longrightarrow Fe_3C + 2H_2$$

Other reactions also occur in a gas atmosphere, but the phenomenon of carburisation is due to the yielding up of atomic or nascent carbon by the carburising medium and its absorption by the steel.

Equilibrium ratios: In the gas carburising process the factor of surface gas-metal equilibrium is better adjusted by varying the gas flow rate, introduction of diluents, interruption of gas flow, and variation of chamber pressure, than by varying the temperature due to the effect of this on gaseous equilibria. The equilibrium ratios for $CH_4 - H_2 + CO_2 - CO$ reactions are given in Fig. 1.

In the $CH_4 \longleftrightarrow C + 2H_2$ systems, the active carburiser (CH_4) becomes less stable as the temperature increases, while in the $2\,CO \longrightarrow C + CO_2$ system, the active car buriser (CO) becomes more stable with increasing temperatures.

Relationship of time to case depths: This relationship is shown in Fig. 2. The figures were obtained on a 3½% nickel case-hardening steel in a vertical natural gas furnace. The curves are almost the same for any of the usual media.

Progress of Commercial Gas Carburising

American metallurgists began to apply the science of gas carburising to production work at the beginning of the present century. The first experimental production furnaces were of the vertical type, the gas being led in at the bottom, but doubts were expressed regarding the success of the process, as heavy and objectionable soot deposits occurred. To overcome this trouble it was decided that tumbling the parts during carburising would shake off the carbon deposit. This, in fact, did result in a cleaner product.

The first production furnaces were put into operation at the end of 1906. These furnaces had a rotating muffle, and used town's gas for both heating and carburising. Messrs. Buick Motors were probably the first to put down a large plant. The equipment, which comprised 10 rotary furnaces, was installed in 1909. Slow development proceeded for a number of years, but it was not until after the last war that rapid expansion of gas carburising commenced. Giolitti's work and the increased demand for automotive products led to wider use of this process.

About 1926, to avoid soot formation, experiments with

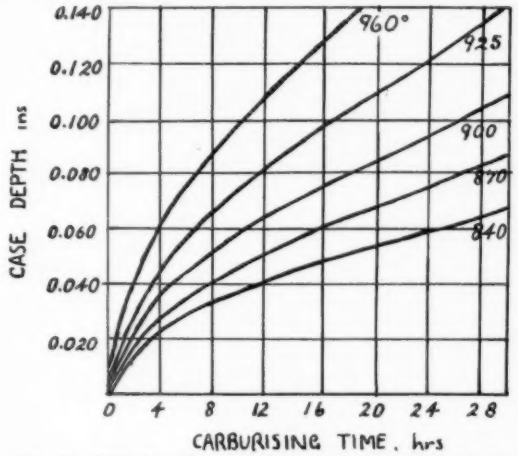


Fig. 2.—Relationship of time and temperature to carbon penetration.
(Sclump.)

diluting gases, such as charcoal producer gas, air, etc. added to propane, were begun, but the use of vertical furnaces was not common until the process extended from the automotive to the heavier industries. Thus, extension of the application of the process has taken place during the last ten or 12 years. In 1930, for instance, Wilbur and Comstock presented a paper on the subject to the American Society for Steel Treating. The evidence they put forward indicated that any hydrocarbon gas, no matter what its available carbon content, could be successfully used for carburising by an on-and-off flow method. Briefly, the principle adopted was that of gas projected through the furnace for a period in a turbulent manner and at high velocity, followed by a period without a gas flow.

Intermittent Surge Method of Gas Carburising

The complicated nature of this "on"-and-"off" method is discussed by Guthrie. A given volume of heavy, dry hydrocarbon gas, at 7 lb. to 15 lb. pressure, is introduced into the retort from 5 secs. to 15 secs., and the gas valves closed from 5 min. to 10 min. while carburising proceeds. This cycle is repeated three times with a 5 min. to 10 min. standby between surges. Then 5% of CO_2 is introduced in the same way for one cycle, clearing the furnace of residual hydrocarbon gas and reactivating the metal surface. The surges of hydrocarbon gas are again begun, followed by a surge of CO_2, the entire cycle being repeated until the desired case depth is obtained. The gas was then shut off to allow diffusion to occur.

The foregoing practice was suitable to high carbon content hydrocarbons which, under ordinary carburising practice, would break down with resultant undesirable soot deposition. A little later, however, R. J. Cowan gave data from experiments with natural gas, propane

and butane, in conjunction with flue gas, and continuous gas carburising resulted from these tests. In these tests it was found desirable to use carbon dioxide in the form of flue gas to obtain a correct carburising gas composition. The principle of the method thus developed was that carbon dioxide reacted with the carbon deposited on the parts to form carbon monoxide, and this gas effected carburisation.

The furnace developed to adopt this method had three zones. At the charging end the components became covered with soot, due to incomplete dissociation of the hydrocarbon gas; in the second zone carburisation took place, while this was arranged to slow down the process to prevent further surface reaction, and to allow the high surface carbon to diffuse inwards to produce satisfactory carbon gradation between case and core.

Reviewing the subject in 1937, G. T. Williams concluded that by selection of carburising gas medium and its regulations, cases of desired depth and characteristics are readily produced. Control of soot precipitation offers several problems, and in most instances these have been successfully overcome. Satisfactory gas carburising will depend largely on the gas medium, and the selection thereof is usually by empirical methods. The following will be the basic consideration in selection of a medium.

1. All commercially-available hydrocarbon gases will supply more than enough carbon to give maximum carburising. Town's gas may in some cases give unsatisfactory results due to variable contents of carburising agent, moisture and carbon dioxide.
2. Hydrocarbon gases will deposit soot if an excess, usually required to give circulation, is used. The tendency to soot deposition is greater with increasing molecular weight.
3. Soot formation may be decreased by holding the excess of hydrocarbon low, volume for circulation being obtained by addition of a non-decarburising or carrier diluent.
4. Carburising to carbon maxima below the austenite solubility limit may be performed by use of hydrocarbon diluted to lower carbon equilibrium.
5. Low carbon cases may also be produced by permitting the high carbon content previously formed to diffuse during one or more periods when no carburising agent is supplied.

Sooting

One of the main problems connected with gas carburising was the formation of soot. The theory is that under certain conditions (gas composition and a lower temperature than that of the steel) carbon can be precipitated from the carburising gas on to the steel. It is deposited in a molecular form, and may range from fluffy soot to a scaly carbon. In this form it is almost inactive, and can only become active for carburisation by recombining with another element to form a compound. Methods are therefore adopted to (*a*) permit soot formation, but to remove it before completion of the carburising cycle; (*b*) to control formation; and (*c*) to prevent carbon deposition.

(*a*) This method has been discussed under the intermittent surge method of gas carburising. As will be appreciated, this method requires precise control, without which decarburisation of the case could easily be effected. Research also indicated that the formation of free carbon on the steel reduced the rate of penetration.

(*b*) In the control of carbon formation, the theory put forward was that if the carburising gases were maintained at a correct composition, uniform temperature, velocity, etc., carbon deposits could be avoided. Such methods are being successfully applied, but they appear to depend on rather narrow limits, which may be too difficult for ordinary heat-treatment supervision. In fact, it is argued that great and continuous care is needed to insure that only the correct amount of the active gas is added to the carrier gas. Obviously, if too much active gas is added to the cooler mixture of the circulating atmosphere and carburising gas, carbon deposition on the steel charge will result.

(*c*) In view of the theory of soot formation, it was considered that if the carburising gas was heated to a slightly higher temperature than that of the steel charge, molecular carbon would not be precipitated. It was found that this method effected case-hardening without sooting, and, in fact, increased the rate of carburisation. This method is successfully operated in at least one large works.

Hydrocarbon gases must be broken up into their constituents to give effective results and, while heat contributes, the gas must be applied at a certain velocity to provide the necessary turbulence. In batch-type furnaces, a fan, suitably situated, is used to effect turbulence. Such a condition is considered to be essential when using an atmosphere produced from a liquid hydrocarbon; otherwise excessive soot deposition results.

Commercial Gases Used in Gas Carburising

Natural gas is probably the most suitable gas for carburising by reason of its relative purity and high percentage or methane. It contains about 80% methane and 5% to 20% ethane. Methane is rather slow in its reactions, which makes for easier control, and this fact, together with large resources in suitable localities, contributed to the initial impetus of gas carburising in America. Under modern conditions, however, natural gas is only used in batch furnaces, and it is cleaned by passing it through linseed oil. Unfortunately, although there are large reserves of methane gas in this country, they are not utilised. The media available in this country includes the liquified hydrocarbons or bottled gases propane and butane; liquid hydrocarbons such as pine oils, petrol, etc.; and town gas.

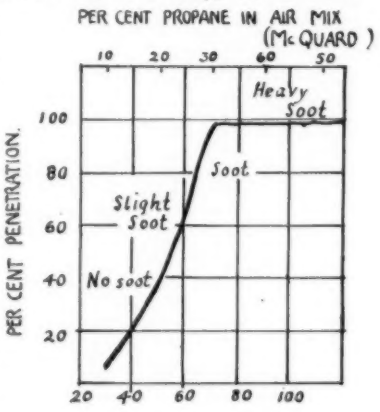


Fig. 3.—Penetration and sooting tendencies of natural gas and propane air mixtures.

Natural gases generally are better than those obtained from oil refineries. The latter contain somewhat high percentages of the unsaturated hydrocarbons propylene and butylene, and, when these gases are present, they cause trouble during carburising due to the acceleration of soot deposition. The bottled or liquified gas propane and butane gasify when they are released from pressure. Suitable hydrocarbon atmospheres produced by liquid hydrocarbons form soot very easily, but in furnaces properly equipped with a fan, this trouble becomes almost negligible. The penetration and sooting tendencies of natural gas and propane air mixtures are shown in Fig. 3.

Town's gas contains up to 50% methane, but owing to variation in decomposition, due to adjustments made to suit other demands, such gases have not been found to be suitable for gas carburising. In some localities where a very uniform supply exists, satisfactory carburisation has been achieved when the gas is enriched by saturation with hydrocarbon. The method of effecting this is to pass the gas through a volatile liquid like benzene.

As has been indicated, when using raw gases rich in hydrocarbons, it is customary to use diluent gases to reduce or prevent the formation of soot. Both charcoal-treated gas and air are used for this purpose. When charcoal and dry air are treated in a suitable producer, a gas

containing about 76% of nitrogen, 33% of carbon monoxide, and 0·3% of carbon dioxide is produced. The addition to this gas of a small percentage of rich hydrocarbon gas provides an effective carburising agent. Since this provides an economical composition, development has been on these lines, but the process is somewhat complicated, and requires additional control because of diluent gases, hence the cheapness and ease with which a richer hydrocarbon has can be diluted with air has led to its common utilisation.

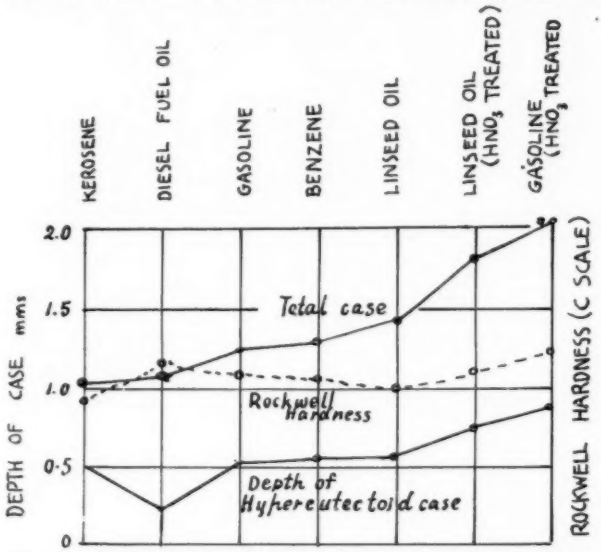


Fig. 4.—Characteristics of carburised case on low-carbon steel made by introducing various oils, drop by drop, in a hot retort.

(B. M. Sulov.)

Oil for Carburising

Moscow Steel Institute was interested in the commercial use of a furnace using oil as a carburising medium. They considered the method sound in localities where natural and manufactured gas was not available, and where the installation of gas producers would be uneconomical. Extensive investigations were carried out on the carburising value of easily obtainable oils, such as petrol, benzene, paraffin and linseed oils, an account of which is given by B. M. Sulov. As in researches with hydrocarbon gases, it was found that many oils deposited a large amount of soot, and investigations were continued to discover an oil which would overcome this defect. The most active oils were those with the lighter oil fraction (according to the specific gravity). Linseed oil was found to be the most active of any common organic product, but its high cost made it commercially unsuitable.

The next step was to oxidise various petroleum products with nitric acid. Considerably more active carburisation resulted, it was discovered, for instance, that petrol, treated in this manner, was more active than either treated or untreated linseed oil. Details of the results obtained are given in Fig. 4. Following these investigations commercial carburising was put into operation using treated petrol as the carburising medium.

An electrically-heated batch-type gas-carburising furnace, using oil to supply the gaseous media, is shown in Fig. 5. The parts to be carburised are loaded in a special container or basket which is located in the furnace. the furnace is then closed and completely sealed. The oil fluid from a small tank is injected into the furnace and its flow is under control so as to produce an actively-carburising cycle or a diffusion cycle. A powerful fan located immediately under the container circulates the gas produced and causes a turbulent action.

Gas and Pack Carburising Compared

The proper operation of modern gas carburising furnaces will produce a case of required depth more accurately than

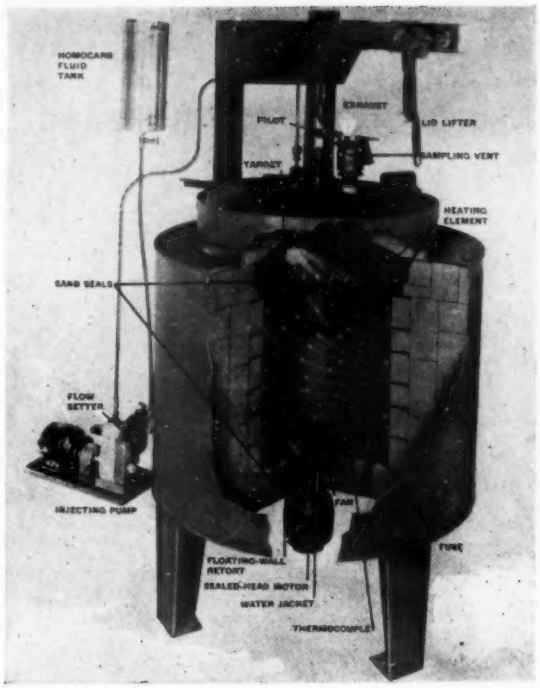


Fig. 5.—Batch type electric heated gas-carburising furnace known as the Homocarb unit.

by pack carburising. The composition of the gas can be varied to produce the desired case, and is under control to a degree that is not possible in pack carburising. The ratio of gross load to net load in pack carburising is of the order of 2½ or 3 to 1, whereas, with gas it is 1 to 1, and the total time in the furnace to produce a given depth of case is much less because of heat absorbed by alloy containers and compound. Thus, with furnaces of corresponding size the gas carburising furnace can deal with a much higher output. While the cost of gas may appear to be high, it may be more than offset by the lower cost of alloy containers, no compound costs, and lower labour charges for handling. Another advantage is that cleaner conditions prevail in a gas carburising shop.

Gaseous Media for Carburising. G. T. Williams.
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American Society of Metals Handbook.
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J. F. Wyzalek and M. H. Folner. *Metal Progress.* September, 1940.

Natural and Artificial Age-Hardening of Duralumin Alloys and their Secondary Age-Hardening

THE hardening phenomenon in duralumin, 5·8% copper aluminium, Lautal, and Mg_2Si-aluminium alloys by tempering aged specimens at various temperatures had been studied by U. Asakura* for times from $\frac{1}{1000}$ to 80 hours, and measuring the hardness values immediately afterwards. The hardness was subsequently measured at intervals, while the specimens remained at room temperatures. It is shown that when naturally-aged specimens are tempered for short periods at 180°, 220°, 260°, 300° and 350° C., the result is a sudden reduction in hardness, accompanied by an increase in the impact value, and a decrease in electrical resistance. On ageing at room temperature, these softened specimens recover their former hardness, and at the same time the impact value decreases and the electrical resistance rises again. The softening and hardening may be repeated several times by alternate operations of short-time tempering and ageing. On prolonged tempering, the hardness of the specimens increases to its former value without having to be subsequently aged, this phenomenon is called by the author,

*Nippon Kinzoku Gakkai—Si, 1940, **4**, 9, pp. 304–314.

The Isothermal Transformation of Austenite in High-Speed Tool Steel

An investigation on the isothermal transformation of austenite in high-speed steel is described. Two typical high-speed tool steels are considered, and the study was made on lines of procedure laid down by Davenport and Bain, of the Research Laboratories, U.S. Steel Corporation, including hardness measurements. The tests carried out were concerned with the decomposition of austenite in the upper and intermediate transformation range; the influence of partial isothermal transformation in the second transformation range upon subsequent martensitic transformation; the influence of process temperature on the transformation process; influence of hardening temperature and of isothermal decomposition at 300° C. on the transformation taking place during tempering.

ISOTHERMAL transformation of austenite in high-speed tool steel has received considerable attention of late. A valuable contribution to this line of research has recently been made by Prof. A. Gulyaev, by publication of a series of tests carried out with two typical high-speed tool steels of the following analysis:

	C.	W.	Cr.	V.
Steel 15-3	0·68	14·86	2·98	—
Steel RF 1	0·63	17·6	4·18	0·98

Decomposition of Austenite in the Upper Transformation Range

The tests concerned with the exploration of the isothermal decomposition of the austenite in the upper transformation range were carried out with samples hardened at 1,280° and 900° C., respectively. The study of the transformation process was made along the lines of procedure laid down by Davenport and Bain (determination of isothermal reaction rate curves) with simultaneous measurement of the hardness. The high-speed tool steel RF 1 was found to show a minimum stability of the austenite at about 710° C. after quenching both from 1,280° and 900° C. For temperatures below 700° C., the stability of the steel increased sharply, and at 600° C. the incubation period (time required for the initiation of the austenite decomposition) was found to exceed five hours. After quenching from 900° C., the maximum speed of transformation therefore lies in the vicinity of 710° C., at which temperature the austenite transforms within 20 mins. If the steel is quenched from 1,280° C., the transformation proceeds very slowly; and even in the range of highest transformation speed, complete transformation is not yet reached after 10 hours. In the isothermal reaction rate curve ("S" curve), the "beginning" curve obtaining with 1,280° C. hardening temperature, therefore lies to the right of the curve obtained with a hardening temperature of 900° C. It was observed that in the zone of highest transformation speed, the incubation period of steel quenched from 1,280° C., equalled 12 mins., while in the case of the sample quenched from 900° C., it amounted to only 9 mins. The influence of high quenching temperature manifested itself in increased length of the incubation period, and also in a very sharp retardation of the pearlitic transformation. This phenomenon of retardation is well illustrated by the Rockwell C curves shown in Fig. 1, where these curves are charted for both quenching temperatures.

As S. Steinberg has demonstrated,[1] the "S" curve can be used as a means for ascertaining the critical speed of hardening. According to Steinberg, the inter-relationship between quenching speed, speed of transformation and degree of under-cooling of the austenite, is expressed by the following equation:

$$\int_{T=O}^{T=t\ (\text{range of undercooling})} dT/(\text{incubation period}) = v_{\text{coo'ing}}$$

This equation constitutes a convenient means for ascertaining the critical hardening speed of steels for which the "S" curve has been established. The application of this method to the high-speed tool steel RF 1 hardened from 1,280° C., is illustrated in Fig. 2. Here

[1] A. P. Gulyaev, "Isothermal Decomposition of Austenite in High-speed Tool Steel," *Metallurg*, No. 9, 1940, p. 43. (Russian.)

Fig. 1.—Length of isothermal treatment versus Rockwell C hardness at various isothermal process temperatures.
1. Steel RF 1, hardened from 1,280° C.
2. „ „ „ „ 900° C.

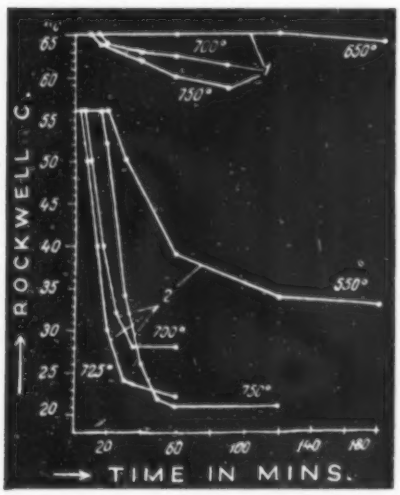


Fig. 2.—Determination of critical cooling speed of steel RF 1. (Hardening.)

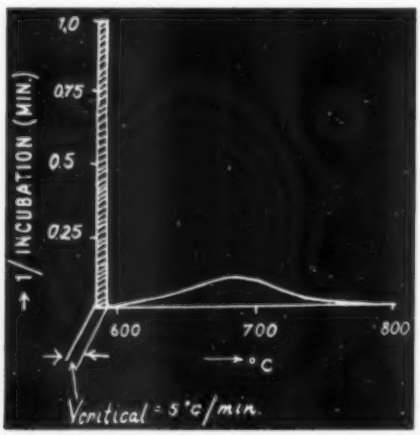
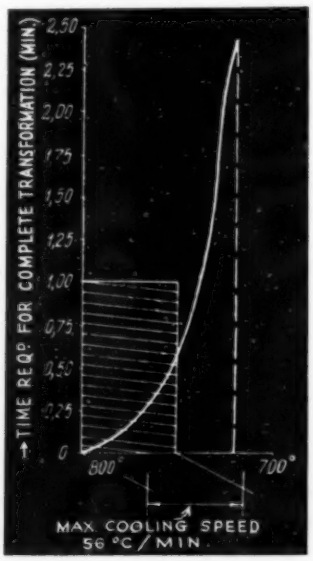


Fig. 3.—Determination of maximum cooling speed of steel RF 1. (Tempering.)



the critical speed is seen to amount to about 5° C. per min. With some modifications, Steinberg's formula can also be used for obtaining the maximum speed of uninterrupted cooling permissible with tempering, which speed must be such as to ensure that the transformation of austenite is completed at a temperature corresponding to that at which the product of transformation has the desired working hardness. This modified equation reads :

$$T=A_1-t_x$$

$$\int_{T=0} dT/(\text{time required for complete transformation}) = v_{\text{maximum cooling}}.$$

where A_1 is the critical point, and where t_x is the lower temperature limit at which complete transformation of the austenite is obtained with maximum permissible hardness. An application of this method to high-speed tool steel RF 1 hardened from 900° C., is illustrated in Fig. 3, where the maximum cooling speed is found as 56° C. per min. This approximates closely to the cooling speed actually employed with this type of tool steel.

Tranformation in the Intermediate Range

The isothermal transformation in the intermediate zone obtained with high-speed tool steel, has been investigated by Steinberg and Zuzin.[2] These workers arrived at the following conclusions :

1. The intermediate zone of transformation lies in the range between 200° and 400° C.
2. In this range, the decomposition of the austenite does not result in complete transformation, and at the end of the transformation process, a considerable residual austenite content remains.
3. The second zone transformation serves to lower the temperature of a subsequent transformation of austenite into martensite.
4. In its outward appearance, the transformation produced in the second range, resembles martensite.

Continuing and enlarging upon the work done by Steinberg and Zuzin, Gulyaev undertook to investigate the transformation characteristics of the aforementioned two high-speed tool steels in the second transformation range. Special attention was paid to the influence of the second zone transformation upon the subsequent transformation of austenite during cooling at various temperatures. In the test made, particular care was taken to clarify the influence of temperature, time, and also of the original hardening temperature.

The Influence of Partial Isothermal Transformation in the Second Transformation Range upon Subsequent Martensitic Transformation

The left-hand sides of Figs. 4 and 5 show the curves of isothermal transformation of austenite at a constant temperature of 300° C. for steel 15-3 and RF 1, respectively ; while the diagrams at the right, show the corresponding characteristics of the subsequent martensitic transformation encountered with cooling for various lengths of time. From these charted records the following deductions were made.

1. Partial transformation at 300° C. has the effect of progressively lowering the temperature of martensitic transformation in conjunction with an increasing length of isothermal transformation of the austenite.

[2] *Metallurg*, No. 1, 1938. Russian.)

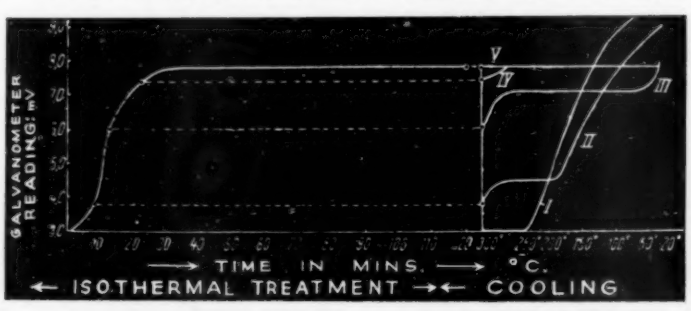


Fig. 4.—Influence of length of isothermal treatment at 300° C. upon austenite decomposition. (Steel 15-3, hardened from 1,250° C.)

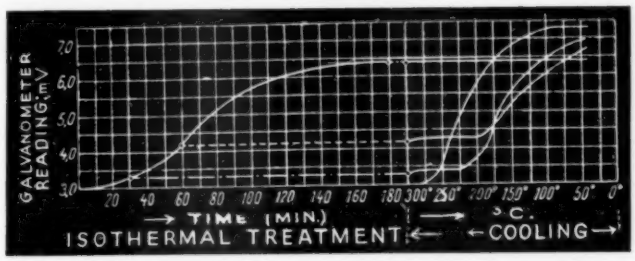


Fig. 5.—Influence of length of isothermal treatment at 300° C. upon austenite decomposition. (Steel RF 1, hardened from 1,280° C.)

2. Extension of the isothermal transformation period to the maximum length of process duration indicated, depresses the temperature of martensitic transformation to below 0° C.
3. The rising characteristics observed at the beginning of the cooling period, indicate a continuation of austenitic decomposition beyond the range of isothermal treatment. But this phenomenon is not observed when the isothermal transformation has been carried out to its maximum possible extent during the isothermal treatment.
4. The charts show that steel 15-3 is quicker to respond to isothermal treatment than steel RF 1, as the transformation of steel 15-3 is ended after 30 mins. treatment at 300° C., while steel RF 1 requires 180 mins.

The inter-relationship at 300° C. between partial transformation with steel 15-3 and Rockwell C hardness after cooling to room temperature is shown in the lower graph of Fig. 6, while the percentage of residual austenite content is charted in the upper part of the chart. The aforementioned depression of the martensitic point after isothermal transformation is responsible for a sharp decrease in the hardness of the steel. Complete transformation at 300° C. leads to an increase in the amount of residual austenite from 24 to 53% after cooling. It also lowers the hardness of the steel from 66 to 52 Rockwell C.

The Influence of the Process Temperature upon the Transformation Process

In Fig. 7 are charted the transformation curves obtained with steel 15-3 after one hour of isothermal transformation at various temperatures ranging from 200° to 400° C. followed by cooling. It is seen that the speed of isothermal transformation and the degree of decomposition of the austenite are greatest at 300° C. Not much different from this result is the characteristic obtained with isothermal treatment at 350° C. It is also seen that both with isothermal treatment at 350° and 300° C. the martensitic point is depressed below 0° C. The speed and the degree of completeness of transformation are seen to fall with increasing temperature, and with 375° C., the transformation is apparently completed after 35 to 40 mins. treatment ; but the degree of transformation is smaller than that experienced with either 300° or 350° C. Further-

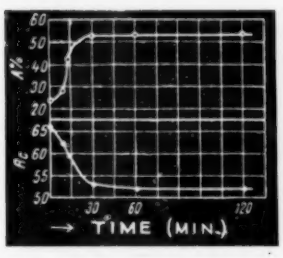


Fig. 6.—Influence of length of isothermal treatment at 300° C. upon Rockwell C hardness and residual austenite content of steel 15-3.

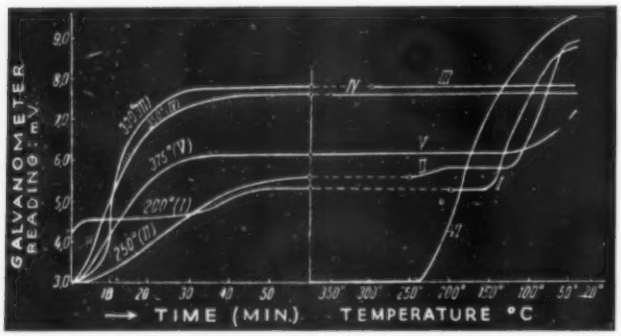


Fig. 7.—Influence of temperature of isothermal treatment. Steel 15-3, hardened from 1,250° C.

more, the temperature at which martensitic transformation begins, is seen to rise with diminished isothermal temperature. If the treatment is carried out at 250° C., the process of transformation slows down considerably, and the graph indicates that the process is not yet completed after one hour's treatment.

The transformation characteristic obtained with 200° C., is seen to start off with a certain amount of initial transformation which is obviously martensitic, and which originates with the cooling from 240° C. (point M) to 200° C. The isothermal transformation into martensite continues for some time. According to Gulyaev, the "isothermal" transformation at this stage is due to a process of temperature and stress equalisation along and throughout the piece, while the isothermal transformation proper sets in after a relatively long incubation period. In this case, a typical intermediate zone transformation takes place, although it occurs below the martensitic point.

In Fig. 8 is charted the intensity of transformation as function of the isothermal process temperature as it was observed in the case of steel 15-3 subjected to one-hour treatment. The upper part of this graph refers to the subsequent martensitic transformation. A comparison of the two curves shows that increased intensity of isothermal transformation is followed by less complete martensitic transformation.

The percentage amount of residual austenite at room temperature obtaining after isothermal transformation, and the respective hardness observed, are charted in Fig. 9 as function of the transformation temperature maintained for a period of one hour. With regard to the aforementioned influence of the isothermal transformation of austenite in the intermediate zone, Gulyaev observed that at 375° C. the isothermal transformation comes to an end after 35 to 40 mins., and that no additional transformation can be obtained by extending the treatment any further. But he also found that such extension is of importance with regard to a subsequent martensitic transformation. This phenomenon is exemplified by the graph

[3] *Journal of Technical Physics*, vol. 2, 1934. (Russian.)

Fig. 8.—Intensity of isothermal transformation (1), and of martensitic transformation (2), as function of isothermal temperature. (Steel 15-3.)

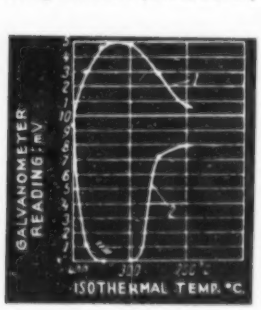
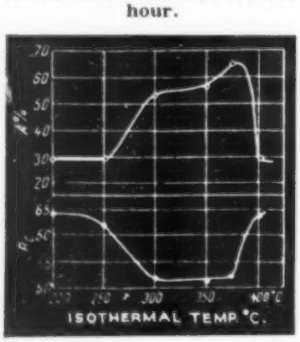


Fig. 9.–Residual austenite content and Rockwell C hardness at room temperature obtained with various temperatures of isothermal treatment for one hour.



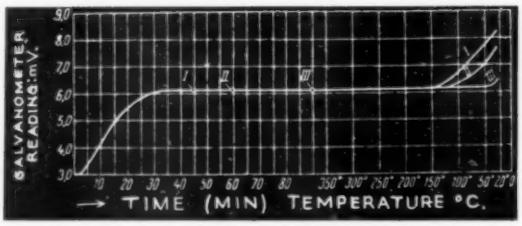


Fig. 10.—Influence of isothermal treatment extended beyondtime required for complete transformation upon subsequent martensitic transformation in cooling period. (Steel 15-3).

reproduced in Fig. 10, which refers to the isothermal transformation of steel 15-3 kept at 375° C. for various lengths of time Here it is seen that three different cooling curves are correlated with a length of isothermal treatment of 10, 25, and 55 mins., respectively.

The conclusion is drawn that the temperature at which martensitic transformation commences, decreases with increasing length of isothermal treatment; and this, in spite of the fact that the increased length of isothermal treatment does not cause any additional isothermal transformation. In view of what has been stated before, the assumption can be made that increased length of isothermal treatment generally accompanied by a depression of the martensitic point, regardless of whether or not an extension in process length results in additional austenitic transformation.

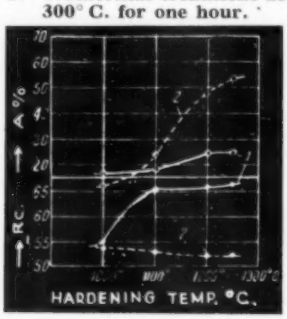
Influence of the Hardening Temperature

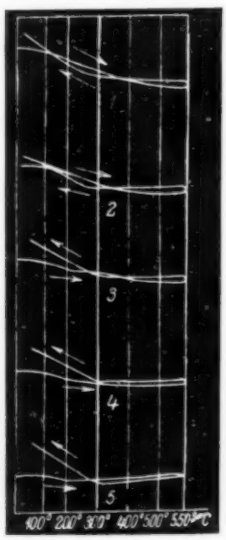
The influence of the hardening temperature upon the result of isothermal transformation is illustrated by the graph shown in Fig. 11. Here it is seen that with a quenching temperature of 1,000° C., the percentage of residual austenite is substantially lowered after the piece has been subjected to one hour's isothermal treatment at 300° C. Gulyaev explains this by the disintegration of primary martensite at these temperatures, which disintegration assists the transformation of the austenite not only during the isothermal process, but also during subsequent cooling. The graph given in Fig. 11 also shows that increased hardening temperature causes a small increase in austenite content and hardness of pieces not subjected to isothermal treatment. As Gulyaev points out, a comparison of the two sets of curves charted in Fig. 11 may be said to furnish convincing proof of the influence of the elevation of the hardening temperature upon the results of the isothermal transformation process.

Fig. 12.—Dilatometer curves obtained with tempering of steel 15-3 at 560° C. for one hour. Steel quenched from 1,260° C. and subjected to varying length of isothermal treatment at 300° C.

Curve 1 — Isothermal treatment at 300° C. for 2 mins.
" 2 — " " " 10 "
" 3 — " " " 20 "
" 4 — " " " 30 "
" 5 — " " " 60 "

Fig. 11.—Influence of the hardening (quenching) temperature upon Rockwell C hardness and residual austenite content.
1. No isothermal treatment.
2. Isothermal treatment at 300° C. for one hour.





The Influence of Isothermal Decomposition at 300° C. upon the Transformation taking place during Tempering

In order to investigate the influence of isothermal decomposition at 300° C. upon the transformation taking place during tempering, samples of 15-3 steel were hardened from 1,250° C. in a salt bath of 300° C. temperature. After isothermal treatment for two to 60 mins., they were tempered in the dilatometer for one hour at 560° C. As is common to all high-speed tool steels, this tempering produced secondary martensitic transformation. The following conclusions were drawn :

1. Increased amounts of residual austenite are reflected in an increase in secondary martensitic transformation.
2. Steels in which the isothermal transformation of austenite has been completed, show a somewhat higher temperature of secondary martensitic transformation than that found with steels in which the isothermal transformation has not been carried to completion. This rise of the martensitic point is not, however, considerable. As seen in Fig. 12, the temperature of secondary martensitic transformation approximates to 250° C. with pieces isothermically treated for two to 10 mins., while isothermal treatment carried out for 30 to 60 mins., causes the transformation point to rise by 50° C. to 300° C. Gulyaev explains this increase by the fact that the residual austenite obtaining after isothermal transformation at 300° C. is less stable than the austenite obtained with the usual method of hardening. In view of the fact that during the tempering process, the residual austenite changes into secondary martensite, and further considering that the secondary martensite possesses a higher red-hardness than primary martensite, Gulyaev concludes that hardening in combination with partial transformation in the second zone, will increase the quality of high-speed tool steel. This should, however, be verified by actual cutting tests.

Electric Semi-Continuous Controlled Atmosphere Furnaces

By E. Hague

(*Electric Resistance Furnace Co. Ltd.*)

The advantages of obtaining fully-annealed metals in a perfectly bright condition are well known, and it is now recognised that the use of controlled atmospheres for the heat-treatment of semi-finished material, or of components, is of tremendous value to metal users. Such furnaces of the bell, continuous conveyer, roller-hearth type are now firmly established, and the semi-continuous furnace, an example of which is described in this article, is another type which has fully justified its installation.

CONTROLLED-ATMOSPHERE furnaces of the bell, continuous conveyer, roller-hearth and pusher types are now firmly established, and this description of a batch unit, or, as it is aptly termed, the semi-continuous furnace, is intended to interest those who, on account of high first cost, limited output, varied or intermittent heat-treatment, cannot justify the installation of a fully-continuous furnace.

Furnaces of the semi-continuous type are already doing highly successful work, and, in addition to the advantage of the initial cost being some 30% to 40% less than the more usual fully-continuous furnace, they have a number of sound technical and economic advantages.

Operating costs are generally in line with those of continuous furnaces and, under certain conditions, they may even be less. This slight advantage is due mainly to the semi-continuous method of working which enables the treatment to be carried out with the furnace doors closed for long periods, thus eliminating the constant atmosphere and heat loss inevitable with open-ended continuous furnaces. Maintenance costs are at a minimum, no mechanical parts being required, as in the case of pusher or conveyer types and the periodic and sometimes expensive renewals are therefore eliminated.

The furnace is extremely adaptable and ideally suited to general-purpose heat-treatment and, in addition, is now being used extensively for controlled-atmosphere brazing. One user of this type of furnace is regularly doing such varied treatment as bright annealing both copper and mild steel pressings, copper brazing steel assemblies and, on occasions, even routine hardening. All these operations are carried out merely by resetting the furnace temperature to suit and, where necessary, adjusting the gas-air ratio to the gas plant to obtain the correct atmosphere for the particular process.

Usually these semi-continuous furnaces are designed for hand operation, and the method of working is very simple. With one tray-load of work in the heating chamber being heated, three tray-loads in the adjoining cooling chamber are being cooled to a safe discharge temperature in the protective atmosphere. The charging cycle consists of first opening the final exit door and removing a cooled

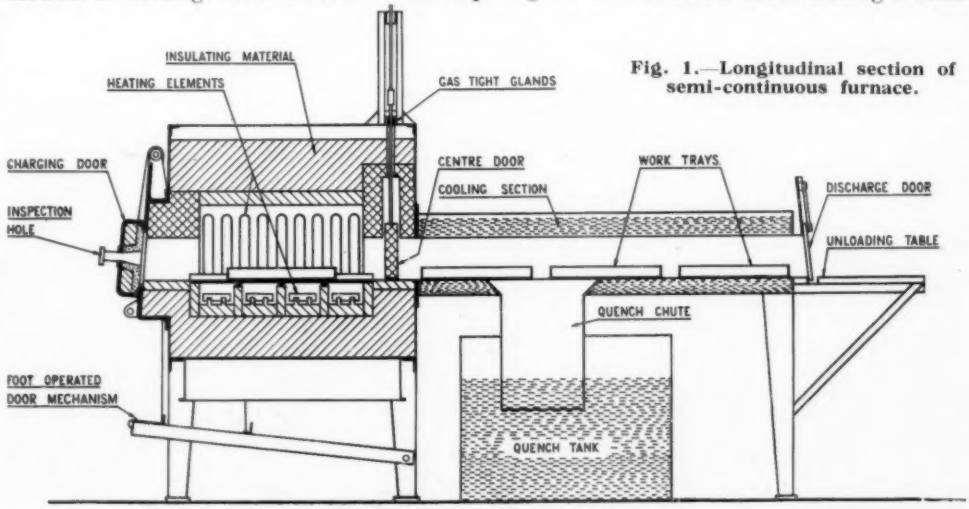


Fig. 1.—Longitudinal section of semi-continuous furnace.

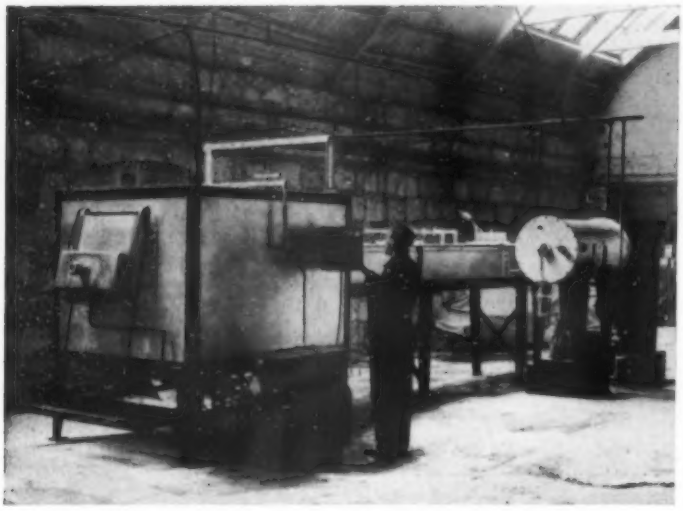


Fig. 2.—Semi-continuous furnace for bright annealing precious metals.

tray from the cooling chamber, then pulling the other two trays one stage nearer the exit door, and so leaving a space adjacent to the centre door. The exit door is then closed, and the operator proceeds to the charging end, opens the front and centre doors and pushes the tray of treated work from the heating chamber to the prepared space in the cooling chamber, and then places a new tray-load in the heating chamber. The closing of the front and centre doors completes the cycle, and the operator then waits the required time for the tray in the heating chamber to be heated before repeating the routine.

The output from the furnaces is governed by two factors, namely, the weight or number of parts that can be loaded on to the tray and the time required for the treatment. It is customary to have more heat available in the furnace than is normally used for the work, as this reserve ensures quick heating up of the furnace from cold.

On account of the limitations presented by the hand-operated design, serious consideration should be given before installing a semi-continuous equipment for applications necessitating either high outputs or exceptionally long furnaces. Many equipments giving outputs of the order of 400 lbs. per hour and having overall lengths of some 20 ft. are already in satisfactory use, but where larger equipments are concerned careful thought should be given before installing semi-continuous equipment to ensure that the advantages of low initial and maintenance costs are not offset by excessive operating costs, coupled with difficult, if not tedious operation.

Description of Furnace

Briefly, the furnace comprises a heating chamber fitted with nickel-chromium tape resisters of substantial section, and an adjoining water-jacketed cooling chamber which is usually three times the length of the heating chamber. Three doors are provided—the charging door, centre door and final exit door—the charging and centre doors may be interlocked and operated by a common foot-pedal, Fig. 1 illustrates this arrangement.

In cases where scale-free hardening may be required as an addition to the more usual treatments such as bright annealing and copper brazing, a quench chute may be fitted in the cooling chamber near the centre door through which parts may be quenched.

To ensure easy passage of the trays from the heating to the cooling chamber, a specially-designed flanged hearth plate is fitted. Trays are provided to suit the particular application, special features sometimes being necessary to ensure correct loading positions for assemblies requiring copper brazing or, where the furnace is being used as a scale-free hardening unit, special loading may be necessary for quench purposes.

Finally, fully automatic temperature control and protection gear is fitted, thus leaving the furnace operator free for other work during the intermittent cycle of operations. Fig. 2 shows a semi-continuous furnace for the bright annealing of precious metals.

Protective Atmosphere Equipment

Reliable and inexpensive protective atmosphere suitable for practically the whole heat-treatment field can be obtained by the partial or complete combustion of raw town's, producer, and, in some cases, even coke-oven gas. The resultant atmosphere consists mainly of nitrogen, but other constituents such as hydrogen, carbon monoxide, and carbon dioxide are present in varying percentages according to the gas air ratio necessary for the metal being treated.

Fig. 3 shows a typical plant of 1,500 cu. ft. delivery capacity, the essential parts comprising:

(*a*) Motor-operated air-gas mixing machine which ensures consistency of both volume and delivery pressure with positive and accurate control of the air-gas mixture irrespective of any fluctuation in pressure which may occur in the raw gas supply mains. This latter feature is most important, as the quality of work obtained from the furnace can be seriously affected by even slight variations in the raw gas supply pressure.
The suction-type mixer illustrated is the result of several years' experience, and is acknowledged to be the most simple and reliable reaons of mixing air and gas for controlled atmosphere work.

(*b*) Combustion chamber specially designed to suit the delivery volume required, and to ensure stable and consistent mixtures ranging from highly-reducing to dead-neutral atmospheres.

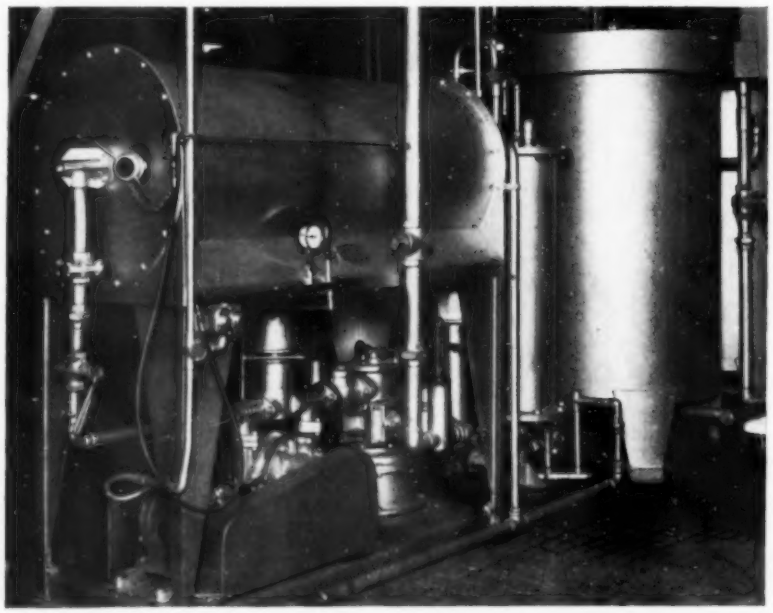


Fig. 3.—Typical gas plant designed to utilise town's gas.

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Intercrystalline Cracking in Boiler Plates

The work summarised in the first section, and dealt with in detail in four succeeding sections in this report, presented at the recent Annual General Meeting of the Iron and Steel Institute, was carried out at the National Physical Laboratory as part of the programme of the Metallurgy Research Board. In addition to an introductory survey of the subject, two sections give, respectively, descriptions of prolonged stress tests on iron and steel specimens immersed in hot sodium hydroxide solutions, and results of the exposure of iron and steel specimens to sodium-hydroxide solutions at high temperature and pressure. The two remaining sections can be regarded as correlative investigations, and deal with strain-etch markings in boiler plate material of acid open-hearth manufacture, and some experiments on the behaviour of specimens of boiler plate and boiler joints subjected to slow cycles of repeated bending stresses while immersed in a boiling aqueous solution. The report is a lengthy one of 66 pages, and in this article only brief reference can be made to its salient features.

Part I.—Introduction

By C. H. DESCH, D.Sc., F.R.S.

THE type of failure which is commonly known as "caustic cracking" is characterised by the intercrystalline path of the cracks. It is most common at riveted joints, especially at rivet holes under butt straps, and often extends along a joint through a number of rivets. The cracks are as a rule easily distinguishable from fatigue cracks and from grooving caused by acid corrosion.

The work of Parr and Straub*, the first report of which was published in 1917, established the main features. It was known, however, that sodium hydroxide could act on iron, liberating hydrogen, and a possible relation to "pickle brittleness" was suspected, but appreciable damage to steel was only found when the concentration of the alkali became high, especially when it was 30% or more, a figure far in excess of anything possible in the interior of the boiler. Parr and Straub put forward the explanation that slight leakage could occur between the plates and the strap, and also round the rivets, and that, owing to evaporation of water at the surface, a high concentration of dissolved salts, in this case largely alkali, could occur, laboratory experiments showed that such concentrations could actually be produced by evaporation in capillary spaces. The fact must be regarded as established. and when a cracked boiler is dismantled, strongly alkaline incrustations can usually be found between the plates and around the rivets. It also appeared that the steel must be in a stressed condition for damage to occur, and laboratory experiments indicated that the stress must have exceeded the yield point. The reports of Parr and Straub have been the starting point of much research work, and their main conclusion that the alkalinity of the boiler water is an essential factor, has been amply confirmed. Besides naturally alkaline waters, many water supplies are rendered alkaline in the course of softening treatments.

In recent years serious failures in power stations have been reported, in some instances resulting in disastrous explosions. In all these cases the water had received alkaline treatment. The likelihood of failure increases with the working pressure and with the age of the boiler, but some very remarkable failures have occurred very early in the life of boilers, even after a few months. Most of the failures have occurred in power stations, but marine boilers have also been known to suffer from this cause, although less frequently. Lloyd's Register has reported eight cases, and its officers suggested that any appearance of broken rivets must be looked on with grave suspicion. The rarity of the defect in marine boilers may possibly be connected with the presence of sea water, which increases ordinary corrosion, but may act as an inhibitor in this form of attack. The power-station accidents have often been very serious, because when one out of a number of boilers is found to have cracked, an inspection of its neighbours usually reveals that they also are cracked, although the damage has not become obvious, and renewal of the whole set becomes necessary.

The work of the National Physical Laboratory on this subject dates from 1917, and Rosenhain and Hanson gave an account in 1920 of several instances of intercrystalline cracking in boilers, associating the effect with corrosion of an undetermined type, combined with the action of stress on the amorphous cement existing between the crystal grains. In the same paper, the cracking of a steel tube which had been in use in a bath of fused nitrates at 300° C., without applied stress, was described, and the similarity of the two cases was indicated. Experiments were undertaken at a later date with the object of examining, one by one, the factors which might conceivably bring about intercrystalline cracking. The possibility had been considered that an amorphous layer between the crystals, if present, might flow under prolonged stress, so producing intercrystalline rupture as an effect of stress and time alone. With the object of settling this point, test-pieces of mild steel were loaded at one-third, one-half and two-thirds of their normal breaking load in an oven kept at 300° C. in an atmosphere of dry air. After five years of exposure none of the specimens had developed cracks, and only the most heavily loaded showed any appreciable extension.

As boilers in use are subject to "breathing" and during intermittent working bending stresses are imposed and removed from time to time, experiments were also put in hand to ascertain whether repeated bending in water or in various solutions could bring about cracking. The experiments were carried out at atmospheric temperature, repeated in air at 200° C. and in liquid at 100° C., but no difference in the number of bends was found in the several solutions in the particular tests, although the type of chemical attack in sodium hydroxide was clearly different from that in water. Again, there was no indication of intercrystalline cracking.

These negative results suggested further lines of investigation. Some boiler failures which had been reported showed the characteristics of corrosion-fatigue, the cracks started from corrosion pits, and this aspect of the problem had been given prominence by McAdam. The breathing and "letting down" of a boiler produce cycles of stress which might combine with the chemical action of the caustic solution to produce typical corrosion-fatigue. In order to test this possibility, experiments were devised in the Engineering Department. Typical corrosion-fatigue failures were produced in an apparatus similar to some which have been found in service, but microscopical examination showed that the cracks were not intercrystalline. Corrosion-fatigue, which had been invoked by some writers as the cause of caustic cracking, may therefore be ruled out in this connection, although it may cause failure under other conditions. It is more likely to occur when the water contains free carbon dioxide, but the present report shows that it is not prevented by the presence of even a concentrated solution of caustic alkali.

A series of experiments designed to test the effect of static stress on steel specimens immersed in concentrated sodium hydroxide solution at 225° to 250° C., is described in the second section of the present report.

Part II.—Prolonged-Stress Tests on Iron and Steel Specimens Immersed in Hot Sodium Hydroxide Solutions.

By C. H. M. JENKINS, D.Sc., and FRANK ADCOCK, M.B.E., D.Sc.

The general plan of this series of tests was similar to that employed by Parr and Straub, but, in order to control the applied stress more accurately, stuffing boxes were avoided, and the loading devices were completely enclosed in the pressure vessel. Electrical attachments were provided to control the constancy of temperature and pressure, and also gave warning when a specimen under stress broke or elongated beyond a certain limit.

The test-pieces used were in the form of plain, perforated or notched strips, about 4·5 in. in length. Except for two round specimens, the tensile tests in air at room temperature were conducted with plain strip specimens. Except for tests on cold-worked material, all the finished specimens were heat-treated *in vacuo* in a sealed silica tube before testing. The test material consisted of a portion of a boiler plate which had developed general intercrystalline breakdown from caustic cracking during service. Analysis of the material used for making most of the tests gave :

Carbon	0·14%	Manganese	0·73%
Silicon	0·02%	Copper	0·067%
Sulphur	0·038%	Molybdenum	Trace%
Phosphorus	0·040%		

Specimens stressed beyond the yield point (as determined at atmospheric temperature) usually broke in a few hours, but no cracks were found other than the single one causing rupture, and there was no sign of intercrystalline breakdown in its neighbourhood. Some experiments were made on specimens with perforations and others with notches in order to examine the effect of concentrations of stress, but no important attack on the crystal boundaries occurred, a fact which disagrees in some measure with the conclusions of Parr and Straub. The authors consider that some other factor, which is necessary to give rise to intercrystalline cracking, was not introduced into the experiments. For example, such a factor might be one which would permit the ready entrance of hydrogen into the steel. Attempts to introduce hydrogen into the steel by electrolytic means have not so far produced general intercrystalline breakdown. The results of these experiments have been difficult to interpret on account of the severity of the general corrosion.

When specimens of normalised boiler plate were uniformly stressed at 225° C. in a solution of high-purity sodium hydroxide to which a small amount of sodium silicate had been added, a very slight amount of intercrystalline crackling took place. This attack was of a shallow type and occurred both in the highly-stressed metal of the test length and in practically unstressed metal near the end of the test-pieces. Specimens stressed appreciably beyond the room-temperature yield stress fractured in a few hours, whilst specimens stressed under similar conditions in a solution of high-purity sodium hydroxide resisted the attack for many days. Owing to the excessive influence of general surface corrosion in these strip specimens, it is doubtful to what degree these results apply to material of plate thickness.

In order to study the effect of stress concentrations, both perforated and notched specimens were stressed at 225° C. in a solution of commercial sodium hydroxide. In the perforated specimens where regions of moderate stress concentration existed, deterioration of the metal was caused by the steady growth of the original non-metallic inclusions in the steel. A different effect, however, occurred in the regions of highly-localised stress in notched specimens; here the material failed owing to cracking, mainly transcrystalline, but occasionally influenced in direction by the presence of a crystal grain boundary.

Heavily cold-worked boiler-plate material, uniformly stressed at 225° C., and exposed to commercial sodium hydroxide solution resisted for long periods a stress which would have caused fracture of a normalised specimen of the same material in a few hours when tested in a similar manner.

Black magnetic oxide formed on specimens of mild steel when exposed to sodium hydroxide solution at 225° C. was found by analysis to correspond closely in composition with Fe_2O_3.

The experiments, using only moderate pressures similar to those in many boilers, having failed to reproduce cracks typical of those found in service, it was decided to produce higher pressures, in view of the fact that a crevice in a riveted joint may become sealed by products of corrosion, allowing a high pressure to develop. Moreover, the temperature in such a riveted seam, exposed to flame, may rise well above the working temperature of the boiler. In order to study such conditions, experiments described in the third section were undertaken.

Part III.—Exposure of Iron and Steel Specimens to Sodium Hydroxide Solutions at High Temperature and Pressure.

By FRANK ADCOCK, M.B.E., D.Sc.

For these experiments small steel cylinders were drilled centrally, the hole filled with sodium-hydroxide solution and closed by washers and clamps, and the specimens were heated to various temperatures. At so high a temperature as 470° C. intercrystalline cracks were readily produced in cold-worked material, whether the sodium hydroxide used was pure or contained the usual commercial impurities. On lowering the temperature to 310° C. intercrystalline cracks were still obtained, but at 225° C. no cracks were found even after a month. It was proved that the attack was due to the penetration of hydrogen, and this gas, reacting with the carbide of steel produced methane, which accumulated until a high pressure was reached. Fully annealed steels were not attacked. These small pressure cylinders were rather difficult to control, and negative results were sometimes obtained. An apparatus was therefore constructed in which the conditions could be maintained constant with greater ease. Small cylinders of the steels to be tested were enclosed in a silver-lined bomb, the reaction space in many instances being limited by packing with silver cylinders, so that the solution was not in contact with any steel other than the specimen under test. Pressures were measured by the deflection of a calibrated silver-faced steel diaphragm. Intercrystalline cracks were readily produced in this apparatus.

The experiments in the silver-lined pressure tube show, according to conclusions by Dr. Adcock, that when fabricated steel plate was acted on, at 410° C., by sodium-hydroxide solution of medium strength (35 parts of NaOH + 100 parts of H_2O, by weight) no intercrystalline cracking occurred, provided that the material was in the annealed condition. On the other hand, the corresponding cold-worked material developed, throughout most of the sample, intercrystalline cracking of a somewhat discontinuous type associated with the carbon-bearing areas and probably identical with that produced by high-pressure hydrogen at high temperatures. This type of cracking was also produced in 17 days at 300° C. Although the cracking at 410° C., and to a lesser extent at 300° C., was associated with the decarburisation of the pearlitic areas, this effect was often absent in the early stages of the attack. The combined pressure of hydrogen and steam often rose to 3 tons per sq. in. in the silver-lined tube towards the end of an experiment at 410° C., and it is

possible that the difference in behaviour between annealed and cold-worked material may hold strictly only for these particular experimental conditions. It is safe to assume, however, that cold-working the steel increases its susceptibility to the hydrogen type of intercrystalline cracking. As mentioned previously, this type of intercrystalline cracking is apparently caused by hydrogen, generated at the metal surface, diffusing into the metal and reacting with iron carbide at or near crystal boundaries. Methane is formed and, being unable to escape by diffusion, collects under great pressure in the intercrystalline crevices, which are thereby extended. The initial stages of this process are favoured by the presence of sub-microscopic cavities believed to be present at the crystal boundaries of as-cast and cold-worked steels. Unless the cracks were in communication with the outer oxide layer on the metal surface they did not contain oxide.

With caustic solutions of much higher concentration, inter-crystalline attack of another type was produced in steel specimens treated at 410° C. These cracks tended to form a more continuous network penetrating the metal from the outer oxide coat. In the early stages, however, the cracks often stopped short at the carbon-bearing regions. These cracks were usually filled with oxide (termed for convenience cracks of the oxidising type), and differed from the hydrogen type of cracking, as they penetrated annealed or cold-worked steel, as far as could be judged, with equal facility. Again, cracks of the hydrogen type were often found throughout the whole mass of a cold-worked specimen, while those of the oxidising type existed in patches always in communication with the outer oxide coat. Both types of cracking may be present in a steel sample, and the effect on the mechanical properties of such a dual attack would be very serious.

It was not possible to make long-period experiments with strong caustic solutions in the silver-lined pressure vessel at temperatures below 410° C., but the experiments made at 350° C., 275° C. and 150° C. in the sealed steel tubes showed how destructive cracking might occur at these temperatures. Although these tubes originally contained the weaker caustic solution (density 1·29), a gradual concentration occurred, owing to the formation of iron oxide and the escape by diffusion of hydrogen.

Since the experiments with superheated steam at atmospheric pressure in the presence of caustic and also in the silver-lined pressure tube with a periodic release of hydrogen did not give rise to serious cracking, it seems probable that a degree of hydrogen pressure is required at some stage in the attack to bring about intercrystalline cracking even of the oxidising type. That the penetration of hydrogen may rapidly weaken steel even at room temperature was shown by an experiment in which a stressed steel wire was made the cathode in an electrolytic bath. Experiments with powdered silver filters demonstrated that dense masses of iron oxide could be deposited at a distance from the place of original formation of this material. This is regarded as important, since the crevices in a boiler may become sealed in this manner and high hydrogen or steam pressures may develop within them. The oxide is apparently cubic Fe_3O_4.

At lower temperatures the oxide penetration in the steel is often partly transcrystalline and partly intercrystalline. The transcrystalline nature of the cracks was especially marked in the specimen treated for 60 days at 150° C. In this connection the author expresses the opinion that destructive caustic cracking in boilers is not always entirely intercrystalline—the structures are often difficult to interpret, and there has been, perhaps, a tendency for writers to select for their micrographs fields emphasising the intercrystalline character of the attack.

In view of the part played by the carbon-bearing regions of steel in giving rise to cracks during caustic attack, the behaviour of carbon-free high-purity iron is of special interest. Unfortunately, the samples of high-purity iron available revealed intercrystalline weakness in cold-working before exposure to caustic solution. In spite of this, no certain evidence could be obtained of the occurrence of the hydrogen type of intercrystalline attack. On the other hand, a sample of high-purity iron readily developed a network of intercrystalline cracks of the oxidising type on exposure to strong sodium-hydroxide solution.

Finally, this investigation, although incomplete, has shown that the reaction between steel and sodium hydroxide solution at elevated temperatures is complex. At least two distinct modes of intercrystalline cracking were detected under laboratory tests, and it is probable that both forms contribute to the caustic cracking of boiler plates under service conditions.

Part IV.—Strain-Etch Markings in Boiler-Plate Material of Acid Open-Hearth Manufacture.

By FRANK ADCOCK, M.B.E., D.Sc., and C. H. M. JENKINS, D.Sc.

In the course of the above investigation, steel which had been deformed at 100° C. was found to show strain-etching when sections were polished and treated with a suitable reagent. Such strain-etching lines, which indicate regions of local deformation, are well known in plates of basic Bessemer steel, but are not usually found in acid open-hearth material, such as was used in this investigation. Polished specimens, magnetised and treated with magnetic powder in suspension, showed that the magnetic stress lines coincided with those produced by etching.

The observations in this short paper have been selected from a larger investigation. Except for one specimen cut from a corroded marine boiler, all the work was conducted on bars and riveted joints made of boiler plate of acid open-hearth manufacture. The analysis made in the National Physical Laboratory was as follows :—

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Nitrogen.
0·20%	0·03%	0·028%	0·036	0·50%	0·004

The bars and joints were from the same cast, but had been subjected to different rolling processes during manufacture. A number of bars were first subjected to various mechanical tests, then the surfaces were ground, polished and etched with Fry's macro-reagent ($CuCl_2 2H_2O$ . . . 90g., H_2O . . . 100 c.c., H.Cl . . . 120 c.c.) for five to 10 mins. at room temperature. Particulars of these tests, together with the results of etching treatment, are given in Table I.

The results suggest that well-defined strain-etch markings are produced only in material which has undergone deformation at elevated temperatures. Repeated bending is unnecessary, as item 4 in the Table indicates that a single bend will enable strain-etch markings to be produced.

TABLE I.

EFFECTS OF MECHANICAL TREATMENT, WITH OR WITHOUT THE SIMULTANEOUS ACTION OF SODIUM HYDROXIDE SOLUTION.

Mechanical and Thermal Treatment of Bars of Boiler-Plate Material.	Result of Subsequent Etching with Fry's Macro-Reagent.
1. As received from manufacturer.	No strain-etch markings.
2. Repeated bending in sodium hydroxide solution at 100° C. (10 million cycles). (Stress range, 2·3 to 18·3 tons per sq. in.)	Well developed strain-etch markings (see Fig. 51).
3. Repeated bending in sodium hydroxide solution at 15° to 20° C. (559,800 cycles). (Stress range, 2·3 to 22·3 tons per sq. in.)	No definite strain-etch markings. Etching of bar after an interval of three months showed feeble strain-etch markings.
4. Bar maintained under steady stress of 25 tons per sq. in. in sodium hydroxide solution at 100° C., for 12 days.	Well-defined strain-etch markings on large part of specimen.
5. Bar bent once at room temperature by plunger of small radius.	No strain-etch markings.

A specially-fabricated joint of boiler-plate material was next examined to ascertain the conditions existing in riveted construction. The joint had not been in service nor subjected to any mechanical tests. A portion of this butt strap was etched with Fry's reagent, after machining away the rivet heads and a small depth of metal. Besides rings round the rivets and fine curved lines resulting from the riveting of the plates, broad etch markings, all lying

roughly in the same direction, covered most of the plate. These are believed to be due to high finishing temperature during the rolling of the plate.

A plate from a marine boiler which had developed a corrosion defect in service, leading to a local concentration of stress, showed strain etch markings corresponding with the distribution of stress around the defect.

Part V.—Some Experiments on the Behaviour of Specimens of Boiler-Plate and Boiler Joints Subjected to Slow Cycles of Repeated Bending Stresses while Immersed in a Boiling Aqueous Solution.

By H. J. GOUGH, M.B.E., D.Sc., and H. V. POLLARD, A.M.I.Mech.E.

It was considered rather unlikely, in view of previous experience, that corrosion-fatigue conditions would result in a definitely intercrystalline type of failure; more probably, studies of the behaviour of specimens exposed to simultaneous *static* stress and corrosion would achieve this result, and this aspect of the problem has received close study in the Metallurgy Department of the National Physical Laboratory. As a correlative investigation, it seemed worth while to carry out a few tests aimed at obtaining some information as to the extent to which corrosion-fatigue conditions may be of importance in boiler failure, in view of the many points of resemblance which have been observed or suspected. The essential difference between corrosion-fatigue conditions and a combination of static stress and corrosion is, of course, that in the former a *range* of cyclic stress or strain is involved, which is absent from the latter; in many cases, a range of cyclic stressing produces much greater destruction and quicker failure than a much higher value, numerically, of static stress. It is extremely difficult to determine—and very easy to overestimate—the extent by which boilers are, in fact, submitted to cyclic stressing; it may, however, be considered as entering into the boiler problem under at least three conditions: (1) In which the boiler shell is considered as being subject mainly to a steady stress, but also to superimposed stress variations due to pressure differences; (2) in which the boiler shell is considered as normally under a steady stress, which is released at intervals when the boiler is "let down"; and (3) a combination of conditions (1) and (2).

Weighing up various considerations, it was concluded that the effect of the study of cycles of *repeated* stress employing a low cyclic frequency would be the most practicable form to use in an investigation designed to examine the degree of correlation existing between boiler failure and corrosion fatigue. Riveted and welded joints were used in preference to simpler forms of test-piece, and it was decided to use full-sized joints made under exactly the same conditions as service joints.

Accordingly, a suitable machine was specially designed and constructed, capable of applying repeated loading, varying from nearly zero to a maximum of 10 tons, at an operating frequency of 35 cycles per min. All tests were made on material taken from one cast of Siemens-Martin open-hearth acid mild steel, conforming to a specification for boiler material of good quality. The tests were made on specimens while immersed in a boiling aqueous solution of sodium hydroxide in distilled water. The initial strength of the solution was 6,000 grains per gallon. Repeated loading tests carried on to endurances up to from 2,000,000 to 10,000,000 cycles, corresponding to total corrosion times not exceeding about 200 days, gave performances which are briefly summarised in Table II.

Considering this summary of numerical results merely as corrosion-fatigue data, the values as recorded and relating to a mild steel of about 26½ tons per sq. in. tenacity, do not give cause for serious alarm. The performance of the riveted and welded joints, in relation to that of the plates, appears to be satisfactory. It must, of course, be realised that endurances of the order of from 10^6 to 10^7 cycles, with maximum corrosion times not exceeding 200 days, undoubtedly underestimate the probable effects of much longer periods of immersion. In fact, the results convey a distinct warning that, as far as possible, precautions must be taken to avoid those conditions suitable for corrosion fatigue, and suggest that, if those conditions are not avoided, then considerable damage may result. The type of fracture obtained in these tests is in marked agreement with damage which has often been observed in boilers in the form of pitting and grooving. On the other hand, the numerical stress values given in the above Table are much in excess of stresses operating in boilers in good practice. Under service conditions, therefore, fairly long times would be necessary to cause serious damage, and careful periodic inspection should go far to reduce the danger of actual fracture in service.

TABLE II.

SUMMARY OF PERFORMANCE OF SPECIMENS.

Type of Specimen.	Maximum Nominal * Range of Repeated Bending Stress under which Samples remained Unbroken (reckoned on Plate). Tons per sq. in.	Corresponding Number of Stress Cycles. Millions.	Corresponding Total Corrosion Time. Days.
(1) ⅜ in. plain boiler plate...	19	8–10	178–205
(2) ¾ in. plain boiler plate...	21	5½	117
(3) Riveted joints of ⅜ in. plate	17	5	102
(4) Electrically-welded butt joints of ⅜ in. plate	19¼	7½	163

* No account has been taken of any local stress-concentration effect at the points of application of the load or at the sudden change of section in the riveted joints at the edge of the cover straps.

In summarising the results of this investigation, the authors state that the principal fact that emerges is that, *under the test conditions employed*, samples of boiler plate, riveted joints and welded joints failed by a process which is essentially that associated with corrosion fatigue; the predominantly intercrystalline type of cracking ascribed to failure by caustic embrittlement was *not* produced. Considerable evidence is available, from certain service boilers, that corrosion-fatigue is a possible cause of danger, and similar fissuring and cracking of this type was reproduced in the present tests. In these tests, the applied ranges of stress which were found necessary to produce fracture were relatively so high—in comparison with nominal working stress adopted in practice—that little cause for alarm would arise from the actual results, although, in this connection, it should be remembered that the test conditions of temperature were much lower than those prevailing in modern practice; also, the maximum period occupied by any one test was small in comparison with normal boiler life. It is therefore possible that under service conditions much more rapid attack might result, and, hence, every effort should be made in operation to exclude, as far as possible, those conditions which would be conducive to such attack. It is of interest to find that, even with the somewhat artificial conditions used in the tests, one example was encountered of the occurrence of cracking in a riveted joint at a position in the interior of the joint and near to a rivet; such cracks have been found in service failures, the crack being of a transcrystalline character as in the present tests.

Practical Conclusions

It has been found necessary to terminate the investigation on the intercrystalline cracking in boiler plates. It may be said that the explanation of caustic cracking originally offered by Parr and Straub has proved to be in the main correct. Dr. Desch states that the following practical conclusions may be drawn from the work described in this report:

1. Intercrystalline cracking in steam rollers is always associated with a high alkalinity of the water Where this is unavoidable, owing either to the originally alkaline character of the supply or to the softening process which has been applied to a naturally hard water, a method of

protection which has proved of value in practice is the maintenance of a ratio of sulphate of alkali above a certain value, depending on the working pressure. No work has been done on the use of other inhibitors, such as phosphates.

2. The steel must be in a condition of stress, the elastic limit having been exceeded, either through an external constraint, as in a riveted joint which has been forcibly brought together, or by internal stress, as in a rivet or in a plate where it has been subjected to riveting pressure. Experience with concentrating pans suggests that cracking may occur, however, in unstressed steel in the presence of very strong alkali.

3. There must be opportunities for the concentration of the solution in capillary spaces. This is the case at riveted joints. A seamless drum presents no such cavities, and caustic cracking has not been observed in such drums, unless at joints or fittings.

4. A high temperature must be reached. This, however, depends on the composition of the solution. Cracking may occur at or near 100° C., or it may need a much higher temperature. In this connection it should be pointed out that temperatures much in excess of the working temperature of the boiler may be reached in a riveted butt-strap joint exposed to the flame.

5. The intercrystalline cracks appear to be of two kinds, the one being clearly due to the penetration of hydrogen formation of methane by its reaction with the carbide of the steel; the other leaving the carbide unchanged, the cracks being filled with black oxide.

6. Cracks caused by corrosion-fatigue, being transcrystalline, are of a different type. They may usually be distinguished by inspection, but a microscopical investigation is conclusive.

• Parr and Straub, University of Illinois Engineering Experiment Station.

Advantages of Aluminium Alloys for Commercial Vehicle Construction Emphasised by an Accident

Much has been said of the advantages of light metals in reducing the unladen weight of commercial vehicles in order to save "dead-weight." In this note the results of an accident to a vehicle, mainly constructed of standard aluminium-alloy sections, indicate that such a vehicle will stand up to more punishment than would a similar vehicle in steel or wood.

IN engineering work the question of determining the most suitable material, and the best distribution of that material, to meet the particular conditions of service, have long been considered essential. These requirements have necessitated the testing of structures and materials in order to provide information which will enable the designer to use those materials to the best advantage. Methods of testing have long been associated with specifications, but there is much controversy regarding their suitability; it has, in fact, been said that none of the properties determined in the most commonly-adopted mechanical tests is an important factor in causing a normal failure in service. There can be little doubt, however, that the methods of testing adopted act as a check on the quality of the material, and assist in the maintenance of a recognised standard.

In the case of structures, as well as the material of which they are composed, the most direct information is obtained from a test to destruction of the completed structure. This is a very costly method, however, and is seldom carried out as a test; but much information is usually obtained when a structure fails in service or when the effects of an accident to a structure produces results that are comparable with a destructive test. In this connection the result of a severe crash on a commercial vehicle, built largely of aluminium alloys has provided striking corroboration of the merits which are generally claimed for this type of construction.

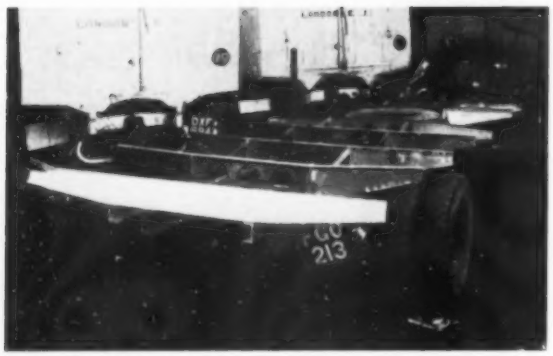
The vehicle, a six-ton composite meat van, collided at appreciable speed with a concrete invasion barricade, probably the most formidable obstacle at present to be met with on our roads. The accident, therefore, from the purely technical point of view approximated to a test virtually to destruction under actual operating conditions. Such a test is, of course, most informative, and provides data which would not be obtained over many years of normal service.

The body of the van is covered in aluminium-alloy sheet whilst the underframe is constructed throughout in aluminium alloys. The design, of a simple but robust type, utilises more or less standardised components, and was evolved by the operators and body builders in collaboration with the Northern Aluminium Company Ltd., which supplied the materials.

General view of the vehicle after the accident.

An advantage claimed for such constructions in aluminium is that they are capable of absorbing a greater amount of energy before permanent deformation takes place than are equivalent structures in other materials. For example, comparing structures of equivalent stiffness n aluminium alloys and steel, the energy required to effect the same degree of deformation is about three times greater in the case of the light-weight structure. Thus, when the two are subjected to the same deforming energy, circumstances which occur in a crash, and which are particularly applicable to the case under review, the stress in the aluminium structure will be considerably less than that in the equivalent steel structure.

This is demonstrated by the result of the crash referred



View of the chassis showing the relatively slight buckling of the aluminium-alloy members.

to, as reference to the accompanying illustrations and consideration of the following points abstracted from the report on the damage to the vehicle will show.

In an impact of such severity, in a vehicle of an older type of construction, the body would normally have left the chassis. In this instance, however, it merely moved two feet forward, and still remained resting on the underframe. The driver, who in most such crashes would have been killed, was merely injured slightly through the deformation of the front of the van, an important point in this connection, revealed by careful inspection, being that if aluminium had been used in place of timber of equal weight in the body construction the burst-through at the front would probably not have occurred.

Just forward of the body, in the top flange member of the main chassis frame, there was a slight collapse in the form of a buckle, this being indicative of the severity of the impact. Examination also revealed, however, that the body had been insufficiently rigidly attached to the bearers over their centre sections, where the longitudinal bracing contributes the greatest strength. At those points the bolts sheared and allowed the impact to be transferred to the unbraced ends of the cross bearers, bending them forward. The damage was such, however, that when repair of the vehicle was reviewed, it was found that the majority of the underframe parts could be reinstated after straightening.

Reference to expert opinion regarding the crash elicited the fact that, from previous experience in similar circumstances, the normal behaviour in the case of a lorry with a wooden body would have been for the body to leave the chassis, overturn in the road, and spill its contents through the roof.

The outcome of this accident has been to confirm a previous decision of the operator to concentrate on the use of aluminium alloys, and to continue with the re-equipping of his fleet with such vehicles when the war-time ban on the use of aluminium has been lifted.

Isothermal Transformation of Austenite in Grey Cast Iron.

THE isothermal transformation of austenite in two grey cast irons has been studied by Hilliker and Cohen.* One of the cast irons was unalloyed, whilst the other contained 2·03% of nickel. The authors discuss the results obtained and present the transformation curves, which show that, as with steel, the presence of nickel decreases the rate of transformation. The hardness of the isothermal transformation products of both irons did not increase continuously with decreasing transformation temperature; it was observed that the products in the 950° to 850° F. range were slightly, but definitely, softer than those formed at transformation temperatures above and below this range.

* *Iron Age*, **147**, pp 43-46.

Electric Semi-Continuous Controlled Atmosphere Furnaces

(*Continued from yage* 26)

(*c*) Cooling tower, which may be of the direct type where the atmosphere is brought in actual contact with the cold water, or, alternatively, of the indirect type using a nest of copper, monel or steel tubing in coil form housed in a gas-tight casing; in this instance, cold water flows through the tubing and the atmosphere over the tubing. On account of periodic renewals of the cooling coils due to a combination of corrosion and sulphur attack, the direct cooler is usually to be preferred. This direct cooler, or scrubber, as it is more generally termed, is perfectly satisfactory for most metals, but, when considering plant where absolute freedom from water vapour is essential, for example, protective atmosphere equipment for high carbon steels, nickel alloys and high zinc brasses, the indirect coil cooler, followed by standard drying equipment such as calcium-chloride towers, activated alumina towers or silica gel plant is to be recommended.

(*d*) Sulphur-removal towers housing trays of iron oxide and specially-treated carbon effectively remove all sulphur present as hydrogen sulphide and, should organic sulphur also be present in the mixture, this is also substantially removed.

In addition to the main items of the plant outlined above, "U" traps, pressure gauges, test points and flow meters are fitted as standard, thus facilitating the checking of both quality and pressures throughout the system, and giving also a constant indication of the gas-air input to the equipment.

The extremely low cost of the processed atmosphere is due to the large amount of nitrogen which is added by the air used for combustion.

When operating on town's gas, three volumes of air to one volume of gas is usual, and, excluding the loss on account of condensation of the water vapour, this means 4,000 cu. ft. of protective atmosphere is obtained from 1,000 cu. ft. of raw town's gas.

Solubility of Sulphur-Dioxide in Molten Copper

THE system molten copper-oxygen-sulphur is of interest from both the practical and theoretical standpoints—practically, because oxygen and sulphur play an important role in the commercial production of copper, and, theoretically, because it offers a chance to study the reaction between an oxide gas, SO_2, and a molten metal. Reactions of this type, such as that between $CO + CO_2$ and molten iron, are important in many metallurgical operations. Again, the determination of any gas-metal equilibrium is of theoretical interest and value insofar as it contributes to the general development of the laws for solution of gases in metals. This problem is being given an increasing amount of attention in modern metallurgy.

A paper by Carl F. Floe and John Chipman* is the first of a series and presents the results of a determination of the solubility of sulphur-dioxide in molten copper at temperatures from 1,100° to 1,500° C., and pressures from about 20 mm. Hg to 900 mm. Hg. The data show that the solubility cannot be interpreted by postulating any simple chemical reaction between the gas and the metal. The equation for solution that would normally be written

$$6\ Cu + SO_2 = Cu_2S + 2\ Cu_2O$$

does not hold, particularly at low pressures. The indications are that this is due to some irregular behaviour of the dilute solutions, which cannot be readily explained on the basis of our present knowledge of the nature of solution of gases in molten metals.

* Technical Publication No. 1,308. *Metals Technology*, April, 1941. Amer. Inst. Min. and Met. Eng.

Zinc Alloy Gravity Die Castings

By E. E. Halls

With judicious selection of alloy composition, co-operation with the die-caster, and simple inspection of the product, the author considers that satisfactory gravity die-cast zinc components are a commercially feasible proposition.

WITH proper attention to design for die-casting, careful consideration of alloy quality and correct technique in the foundry, zinc-base alloys have established themselves in recent years as sound materials for pressure die-castings, and heavy production loads on machine shops have proved zinc alloy die-castings to be indispensable under present conditions. Not only can this series of alloys provide all that is required for many fastidious components with respect to mechanical properties and to accuracy of dimensions, but also fabrication problems are enormously simplified with the elimination of much machining, thereby increasing production rates many times. Furthermore, numerous articles hitherto die-cast in aluminium alloy can be turned over to zinc with little difficulty; often steel and brass-machined parts can be redesigned for die-cast zinc with economy, in addition to the advantageous time factor. However, there are numerous articles that are required in relatively small numbers for which pressure die casting tools are not warranted, aluminium alloy may not be available for gravity methods, yet built up, welded or machined methods of manufacture are slow, expensive and cumbersome, and lock up plant that can be used to better advantage. Gravity castings are possible in such instances. One of the features of pressure die cast-zinc alloys, of course, is the high density, compactness and freedom from porosity that is secured. Quite the same degree of solidity, of course, is not practicable in gravity die-casting, and therefore, in general, the latter procedure is not advocated. Under reasonably controlled conditions, however, the extent to which mechanical values are forfeited is small and, usually, it is of little or no consequence in the cases concerned. It can be stated, therefore, that with judicious selection of alloy composition, co-operation with the die-caster, and simple inspection of the product, satisfactory gravity die-cast zinc components are a commercially feasible proposition.

Zinc alloys in engineering have become re-established largely by virtue of the development of the Mazak series of alloys, these being patented compositions of National Alloys, Ltd. For stability, freedom from ageing effects, and, without propensities to grow or shrink, to crack or laminate, the first fundamentals are virtually freedom from the dangerous impurities of cadmium, tin and lead and correct alloy composition. The Mazak series of alloys for pressure die-casting give these features by virtue of ultra-high purity ingredients and the proper balance of copper, magnesium and aluminium in a series of compositions to meet various needs. Even under war conditions, Mazak No. 3 is available with its pre-war guarantees to suit requirements demanding high dimensional stability and permanence of mechanical properties, and the general purposes alloy Mazak No. 5 is only changed with respect to the grade of aluminium employed, and is, therefore, available under the new distinguishing name of Durak No. 5, but with all its properties and performance unimpaired. These features are mentioned because up to the time that research established the reasons for the shortcomings in zinc die-castings, and field trials confirmed the results arrived at, zinc-base alloy was regarded as an unsuitable material for general engineering purposes due to its proneness to intercrystalline cracking, swelling and disintegration. Consequently, it is stressed that the principles that hold good for pressure die-castings must, in general, obtain in the case of gravity castings. Again, technicians would broadly consider gravity zinc castings in an unfavourable light, chiefly because the high density imparted by the pressure process not only brings out the best mechanical properties in the material but also because complete freedom from porosity in these dense components provides an added resistance to corrosive attack. On the other hand, no technician would condemn a gravity casting, and can only criticise it to the extent pointed out in the opening paragraph, and all would accept it in the circumstances indicated. Actually, service has established them as satisfactory. Nevertheless, it can be seen that close attention must be given to alloy compositions, freedom from impurities and foundry technique and conditions to ensure that no contamination occurs that is likely to upset the service stability of the component produced.

Co-operation with the die-caster is, of course, essential in order to reach agreement upon this composition, because the foundry aspects must be taken into consideration, especially the property of "castability." The Mazak series of alloys are, of course, put forward for pressure die-casting, and while it is probably correct to state that the No. 3 alloy, being copper-free, would present some difficulties in gravity casting, the general purposes alloy No. 5 should prove successful. However, most casters in this country prepare their own mixtures, and in consequence they do not contain the magnesium ingredient, which is useful in helping to suppress intercrystalline corrosion, although its presence is not essential if high-purity zinc is employed, and if copper is present to the extent of 1 to 1½%. The features to ensure are the normal content of aluminium (nominal 4%), copper restricted to the region just mentioned, and certainty that this composition is regularly worked to. Haphazard alloying, as shown by commercial castings containing, from 4 to 10% of aluminium, and 0·1 to 4% of copper, should not be tolerated. Purity of the alloy, largely determined by that of the zinc employed, can only be ensured by insisting upon the same impurity maxima as specified for pressure die-castings. A typical compositional specification is as follows:—

Alloying Elements.	Minimum. %	Maximum. %
Aluminium	3·9	4·3
Copper	1	1·5
Impurities.		
Iron	—	0·075
Lead	—	0·003
Cadmium	—	0·003
Tin	—	0·001

In the case of pressure die-castings, it is the established practice to assess their durability by means of a steam-ageing test. This isof an empirical nature, but it distinguishes between good, bad and indifferent castings; within limits t indicates what faults exist, and has the confidence-inspiring aspect that castings withstanding the test will give the service expected of them. The same test can be applied to gravity castings. It comprises subjection of the test specimens to an atmosphere of water vapour at 95° C. for a continuous period of 10 days (240 hours). The test chamber can be a copper or monel metal tank, well lagged, with the reservoir of water in the base heated by electric immersion heaters and automatically controlled from a point in the atmosphere above the water, and in which the specimens are suspended by means of zinc or aluminium wire. A tight-fitting copper cover, properly lagged, closes the tank. Automatic maintenance of water level is provided. No wood or other organic

matter should be within the test enclosure. Under these test conditions, impurities or faulty alloy composition are revealed by readily perceptible intercrystalline cracking, superficial cracking or blistering, or by delaminating. Instability of dimensions is shown by growth which can be checked before and after test by measurements, using a micrometer or other suitable instruments. Fracture is also useful to examine. Blow-holes are revealed, as also will be poor flow of metal due to wrong design of moulds or air-pockets; weakness and appreciable blackening, often completely through the section, will be experienced in such cases. With copper present as an alloying element, a marginal blackening, similar in appearance to case-hardening in mild steel, will be apparent to a depth of a few mils, but of marked uniformity.

Under the steam test the dimensional stability obtained from pressure die-cast Mazak No. 3 (maximum expansion of 0·001 in. per inch) cannot be expected, and something of the order of an increase of 0·006 in. per inch may be experienced. The other features of the test, and these may be regarded as "visual" or "qualitative" observations, should be upheld—viz., no cracking, flaking, laminating or blistering, and no volume deterioration as shown by extensive penetration of the steam upon fracture.

Regarding dimensional limits, a tolerance of 0·003 in. per inch, with a minimum value of 0·005 in., is normally allowed on all linear dimensions. This, of course, is customarily expressed as a unilateral tolerance, that is, minus 0·000 in. plus 0·003 in. Nominal thicknesses are likewise unilateral, with a plus limit of 5%.

Gravity zinc-alloy die-castings represent a very small percentage of the zinc casting output, but they are, nevertheless, extremely important by virtue of the need they fulfil. Often they serve a critical purpose, and provided that what limitations they offer are duly borne in mind, and quality control is exercised along the lines indicated, satisfaction is ensured. At the same time, of course, there must be *no* tendency to change from pressure to gravity die-cast components.

Saving More Tinplate

AN additional annual saving of from 30,000 to 40,000 tons of tinplate is expected to result from the extension of the restrictions placed on the use of uneconomic and non-essential tinplate containers under a new Order, made by the Minister of Supply, which came into force on Monday, April 28. The Order (the Control of Tins and Cans (No. 4) Order, 1941), which cancels the three previous Orders, incorporates new tables of the British Standards Institution Schedules relating to size and shape of containers, and prohibits the use of tinplate for packing a considerable range of commodities.

While the provisions of the Order are similar to those of previous Tins and Cans Orders, there are three important changes:

1. Responsibility for carrying out the terms of the Order is now placed upon the packer of the commodity as well as on the manufacturer of the container.
2. Partly-made containers or articles which are not now permitted by the Order must be completely finished within three months after the date of the Order.
3. A packer using a permitted container must pack it with the nett weight or capacity specified or in some cases with both the nett weight (or capacity), and the ullage so specified in the B.S.I. Schedules.

There will be no more tinplate containers for such commodities as liquid coffee essence, meat extract cubes (except medicated), corn plasters, chocolate laxatives, fishing bait, incense, gramophone needles and sparking plugs.

The Order is obtainable, price 2d., from H.M. Stationery Office, York House, Kingsway, W.C. 2, or through any bookseller.

Tungsten Mining in Nigeria

ALTHOUGH it is known that wolframite occurs in the Nigerian tinfields, and there was a small output during the Great War, production was not officially recorded until 1934, and was very small until the second half of 1938. Since then, according to the current Bulletin of the Imperial Institute, wolframite veins have been opened up in several districts, and in 1939 a total of 240 tons of concentrates was produced.

Cassiterite, columbite and wolframite belong to the same primary mineralisation in Nigeria, but whereas the two forms are worked almost entirely from alluvial deposits, wolframite is only obtained from vein deposits and adjacent eluvium, as it does not persist under alluvial conditions. In Banchi Province in the district around Kalato, about 60 miles north of Jos, several cassiterite-wolframite lodes have been exposed with strikes totalling more than three miles. At Liruen Kano, in the southern part of Kano Province, the Liruen main lode has now been opened up by opencast mining for over three miles along the strike. Mining consists of working lode outcrops by opencast. The ore is crushed by hand, and panned, and the wolframite separated with magnetic separators. Experimental parcels of this concentrate have been treated successfully in England by the Murex process.

The Corrosion of Copper and Some Copper Alloys in Atmospheres Highly Polluted with Coal Smoke

(*Continued from page* 11)

to conflict as to the actions giving rise to copper residues. A few laboratory experiments were therefore made, using samples of the alloys 11 and 2B and three further aluminium bronzes. The compositions of the alloys used are shown shown in Table IV.

TABLE IV.

Metal.	Copper. %	Aluminium. %	Iron. %	Structure as Received.
Sheet 11	91·0	8·6	0·3	α + discontinuous eutectoid
" 2B	90·3	9·1	0·5	α + continuous β
" BGY	91·0	8·5	0·33	α + discontinuous eutectoid
Bar BFB.....	90·6	9·3	0·05	α + continuous eutectoid
" BIE	93·5	6·4	0·02	α

In addition to work on the alloys as received, samples of some of the alloys were heated to 900° C. and then quenched in water, or cooled in the furnace to 700° or 500° C., and quenched. There was thus obtained a series of microstructures which included homogeneous α, $(\alpha + \beta)$ in continuous networks, $\alpha + (\alpha + \delta)$ eutectoid in continuous networks, α with dispersed β masses, and α with dispersed eutectoid masses.

Most of the experiments were made with sulphuric and hydrochloric acids of from 0·001 to N-concentration, but some were made in neutral solution. In general the specimens were half immersed in the corroding liquid, specimens of rod being mounted vertically with the lower portion held in paraffin wax and specimens of sheet being suspended vertically. Some experiments with drops of solution were also made. The results of these experiments show that, as in the tunnel exposures, the existence of a continuous two-phase structure in aluminium bronze increased the rate of penetration of corrosion by acids in the laboratory. This was true whether the second phase was β or eutectoid. The copper deposits sometimes produced during the acid corrosion of these bronzes may either be a residue left by the solution of aluminium from a corroded phase, or an electrodeposit formed at water lines or other zones which have become cathodic to other portions of the immersed metal.

It is noteworthy that Mr. S. C. Britton, M.A., has been awarded the Herbert Jackson Prize of the London, Midland and Scottish Railway Company for 1940, in recognition of the work carried out and discussed in this paper.

Reviews of Current Literature

X-Ray Analysis in Industry

THE earliest application of X-ray analysis was to the determination of the atomic arrangement in crystalline structures, and this work has had far-reaching results in many branches of science. Of recent years this powerful tool of the physicist has been used to investigate many other characteristics of the solid state such as the identification of crystalline constituents of minute samples, the structure of alloys, the identification of intermediate products in chemical processes, the identification of allotropic changes in refractories, and the determination of sub-microscopic crystal size and orientation. A new field, hardly explored at all as yet, is that of the sub-microscopic structures within each individual crystal, such as occur in age-hardening and other types of imperfect phase precipitation in the solid state. Such structures profoundly influence physical properties and hence are of great interest.

The importance of this subject, particularly for the present war effort, has led to a widely-expressed desire for closer collaboration and sharing of experience between those concerned with the subject. This desire is being met by the publication of a series of papers invited by Sir Lawrence Bragg, President of the Institute of Physics and a pioneer in this field, and will be published by the Institute in two special issues of the "Journal of Scientific Instruments" (which journal is now partly devoted to the applications of physics in industry). Each of these numbers will be enlarged to double the normal wartime size; the first group of papers will be published in the May issue, and will deal with the applications of X-ray methods as applied to a wide range of industrial problems. The second group, which will appear two or three months later, will deal with the technique of the methods and some recent developments.

Copies of these special issues may be obtained from the Institute of Physics (temporary address at The University, Reading), price 2s. 8d. each, post free, or from any bookseller. Early application for copies is advised owing to the limitation of paper supplies.

The Analysis of Minerals and Ores of the Rarer Elements

SINCE the publication of the first edition of this book, 21 years ago, nearly all the elements then considered have found important and permanent applications in the arts, while the analytical chemistry of the great majority have made such rapid strides that an adequate treatment of the subject has necessitated an almost complete rewriting of the original text to produce the present edition, and the authors are to be congratulated on the result of their work.

With a view to attempting further progress in a field where so much remained to be done, the authors subjected the first edition to a very critical survey immediately on its publication, and having reached the conclusion that none of the rarer elements presented more complex unsolved analytical problems than tantalum and niobium, they set out on a systematic investigation of earth-acid analysis. This task absorbed 17 years of uninterrupted research work, the results of which were published in a series of 33 papers, and subsequently published in the form of a monograph. As an outcome of this work the authors were able to discard all the older unsatisfactory procedures and literally write a new chapter in earth-acid analysis, but also to add fresh knowledge to the analytical chemistry of several mineral associates of tantalum and niobium, such as tungsten, titanium, zirconium, uranium, vanadium and beryllium.

This manual, which is properly claimed to be for analytical chemists, metallurgists, and advanced students, represents in the main the fruit of the authors' practical experience, since comparatively few processes have been included with which they are not personally familiar. The section on the platinum metals, for instance, which has been completely rewritten, can fairly claim to be the most up-to-date guide to the practical analysis of this group. Of the less familiar elements, the only two with which the authors have no practical experience are rubidium and cæsium—thus, revision of the sections on lithium, rubidium and cæsium has been carried out by Dr. Roger C. Wells, an authority on the rarer alkali metals: it is noteworthy, too, that the revision of the sections on molybdenum and tungsten was carried out by Mr. D. A. Lambie, B.Sc., A.I.C., who has devoted much study and research to the analysis of these metals.

In the present edition the presentation of the text matter has been radically changed; instead of each element being considered separately, as in the first edition, elements that are always found associated are discussed in one and the same section. Thus, such associated elements as rubidium and cæsium, the rare earth metals, zirconium and hafnium, niobium and tantalum, selenium and tellurium, and the six platinum metals, are treated in this way, and the presentation is more helpful. Another alteration, which will doubtless meet with a mixed reception, concerns the tabulated scheme for the complete analysis of minerals of the rarer elements, this has been replaced by directions for carrying out this work.

The scope of this book has been enlarged by the inclusion of the analysis of ferro-alloys of vanadium, molybdenum and tungsten, and the determination of these elements in steels, as well as the analysis of commercial selenium tellurium and the platinum metals. In its present form this book will rapidly become recognised as a standard work of reference on this subject.

By W. R. Schœller, Ph.D., F.I.C., and A. R. Powell. Published by Charles Griffin and Company Ltd., 42, Drury Lane, London, W.C. 2. Price 18s. net.

Protective Films on Tinplate by Chemical Treatment

A PROTECTIVE film is produced on tinplate by immersion in a hot chromic acid solution after preliminary degreasing, or by immersion in hot alkaline phosphate-chromate solution, which simultaneously degreases and films the tinplate. The film prevents discoloration of tinplate by the sulphur-containing foodstuffs and to some extent prevents bleaching of the artificial colouring which is added to certain canned foods. The films produced in the alkaline solutions also inhibit rusting of the tinplate at discontinuities in the tin coating.

When sulphur-containing foodstuffs are packed in tinplate cans, the insides of the cans generally become stained during the hot sterilising process; this staining may be accentuated by subsequent storage. In addition, the food, if coloured, may be bleached to some extent due to reduction of the colouring matter by tin. A special sulphur-resisting lacquer is often applied to the tinplate to avoid these difficulties.

Other means of protection include an electrolytic process whereby an invisible anodic film is produced on the tinplate surface of the can, rendering it resistant to sulphur staining; using dilute ammonia as the electrolyte the film is produced in a few seconds. In another method of protection, a film consisting of a hydrophilic colloid, such as starch, is electrodeposited from a solution in aqueous sodium aluminate. Both these methods are rapid, but require complicated equipment.

It was thought that production by a non-electrolytic method of an oxide film resistant to sulphur staining would be simpler in practice, and it was found that such films were produced by immersing tinplate in hot solutions containing hydrogen peroxide, sodium perborate, sodium percarbonate, picric acid, potassium permanganate, or chromic acid. The first three compounds were unstable

in solution, and picric acid and potassium permanganate caused some staining of the tinplate, chromic acid, however, was stable, caused no staining, and gave films which resisted sulphur staining.

The degree of protection afforded by the oxide film was found to vary with the temperature and concentration of the solution, and the time of immersion. Tests made with processed peas, gelatin-albumin mixture, and cold hydrogen sulphide solution showed that with a 10% solution adequate protection was secured by immersion for 10 mins. at boiling temperature, 15 min. at 90°, 25 min. at 80°, or 40 min. at 70°. Increasing the concentration of the filming solution from 10% to 35% reduced the filming time at 90° from 15 to 10 min.; a 5% solution, however, required 30 min. In all subsequent experiments with chromic acid solutions the filming treatment consisted of 15 min. immersion in 10% chromic acid at 90°.

Experiments have also been carried out with a view to developing alkaline solutions to film tinplate. It was found that hydrogen peroxide and perborates in alkaline solution slowly gave resistant films, but the solutions were unstable; picrates and permanganates also gave resistant films, but were liable to stain the tinplate, and the solutions were again unstable; chromates, however, were stable, and gave protective films. Solutions containing potassium chromate and sodium carbonate or sodium disilicate gave some degree of protection, but also some etching; potassium chromate and sodium hydroxide gave good protection, but considerable etching; potassium chromate and tri-sodium phosphate gave very good protection and no etching. A solution containing sodium hydroxide, sodium citrate, and potassium chronate also gave very good protection, but no etching; this solution, however, was unstable owing to the oxidation of the citrate by the chromate. A solution containing potassium chromate and tri-sodium phosphate, therefore, was the only one found which produced an adequate film, did not etch the tinplate, and did not decompose.

The best results were obtained with a solution containing 100 g. per l. of crystalline trisodium phosphate and 20 g. per l. of potassium chromate; with such a solution at 90° a sufficiently protective film was produced in 15 mins.

Full details of these developments are given in Publication 104, issued by the Tin Research Institute, Fraser Road, Greenford, Middlesex, from which copies are available.

Electrical Engineers' Compendium

THIS compendium of facts and formulæ relating to electrical, general, mechanical and hydraulic engineering, and in a vest pocket form for easy reference, will meet a demand which has existed for many years. In collating and arranging the data the authors have given full recognition to B.S.I., I.E.E., and E.R.A. rulings and ratings, and they have included other reliable information on many branches of engineering which has been brought up to date. It is published by the associated companies—The London Electric Wire Co. Ltd., Smiths, Ltd., Frederick Smith and Co., and The Liverpool Electric Cable Co. Ltd., and is admirably produced. Copies are available on application to the Publicity Department of the Companies at 19, Queen Anne's Gate, Westminster, London, S.W. 1, or to any of their provincial branches, price 3s. 6d. net.

Tin Research Report

Improvement of Tinplate

THE work of the Tin Research Institute during 1940 was directed largely to adapting tin to war industries, but progress in the metal's more normal applications was well maintained. A notable development mentioned in the Institute's Annual Report, which has just been issued, is a means of preventing the blackening of the insides of meat cans. The tinplate is put into a boiling chemical solution which rapidly produces a film of oxide on its surface; this oxide is so thin that it does not visibly alter the bright tin surface, but it effectually resists blackening.

A recent discovery of the Institute is the so-called "speculum" plating, a brilliant silvery plating obtained by the electro-deposition of a tin-copper alloy containing about 45% of tin; it is not quite so tarnish-resisting as chromium, but it is more easily repolished. The commercial development of this plating process has been hindered by the war, but two plants have been installed in England, and others are being discussed.

Researches in 1940 showed that difficulties met with in soldering electro-tinned surfaces are due to the coating being too thin; the troubles disappear if the coatings are reasonably thick, and it is quite easy to make them so by using one or other of the modern electro-tinning baths described in the Institute's handbook No. 92, "Electro-Tinning." Tin coatings are now being applied electrolytically to engine pistons and rings because they greatly reduce the wear during running-in, and assist in retaining the lubricating film.

The anti-friction qualities of tin are best known in connection with the bearing metals consisting mainly of tin with some antimony and small amounts of other metals. Work in the Institute laboratories has greatly enlarged the range of bearing metals available, but it remains to carry out engine tests to decide which shall be used in particular cases. The factors affecting adhesion of these bearings to the steel or bronze backing-shells are being studied, and are now better understood. Efforts to find a better under-water bearing for ships have led to the discovery of an alloy of outstanding superiority, having a higher percentage of tin than now used.

During the year many requests for advice and assistance were received from firms and Government departments; a fairly large proportion were from firms taking up hot-tinning. A handbook "Hot Tinning" was produced towards the end of the year, and has since been in big demand. Larger scale equipment for tinning by this method, and also be electrodeposition, has been installed in the laboratories of the Institute, and the processes are now being satisfactorily demonstrated to industry.

Institute of Metals.

May Lecture.

THE Annual May Lecture of the above Institute will be delivered at Oxford, on May 28, by Dr. F. E. Simon, Reader in Thermo-Dynamics at Oxford University. He will deal with his own experimental work during the last few years. This is the first time the May Lecture has been delivered out of London, and it is hoped that members will endeavour to be present.

ENGINEER with first-class practical experience in hot rolling and rod drawing of non-ferrous alloys—capable of developing and improving upon the existing methods of production—required to take charge of the department. Permanent and progressive position offered for suitable applicant. Box No. 200.

ENGINEER fully conversant with drop forgings, hot brass pressings, die design and modern production methods will find a progressive position with a rapidly developing concern. Box No. 201.